THE NATURE OF RADIOACTIVE FALL-OUT AND ITS EFFECTS ON MAN

HEARINGS

BEFORE THE

SPECIAL SUBCOMMITTEE ON RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

EIGHTY-FIFTH CONGRESS

FIRST SESSION

ON

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

MAY 27, 28, 29, AND JUNE 3, 1957

PART 1

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THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

MONDAY, MAY 27, 1957

Congress of the United States,
Special Subcommittee on Radiation of the
Joint Committee on Atomic Energy,
Washington, D. C.

The special subcommittee met, pursuant to call, at 10:05 a. m., in the caucus room, Senate Office Building, Hon. Chet Holifield, chairman of the subcommittee, presiding.

Present: Representatives Holifield, Durham (chairman of the Joint Committee), Price, Cole, Van Zandt; Senators Anderson, Jackson, Hickenlooper, and Bricker.

Present also: Professional staff members, James T. Ramey, executive director, George E. Brown Jr., Paul C. Tompkins, consultant, and Hal Hollister, staff technical adviser.

Representative Holifield. The committee will be in order.

This is the opening day of public hearings by the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy on the nature of radioactive fallout and its effect on man. The primary purpose of the hearing is to bring together in one forum competent scientific opinion on the various major aspects of the fallout problem. An effort has been made to have a well-balanced presentation, with witnesses representing varied points of view within the scientific community.

It is the committee's intention through the presentation of expert scientific testimony, to trace the fallout cycle from the moment of the nuclear explosion, through the scattering of radioactive debris in the atmosphere, its descent to the ground, and finally its effect on human beings, livestock, and agriculture. Each of the various scientific areas and disciplines involved will be considered in sequence and an attempt will be made at the conclusion of the hearings to bring together, through general discussion, some of the major points developed at the hearings. In particular, the committee hopes to be able to delineate those areas where we have knowledge from those where we have little or no knowledge, with a view to determining the areas of research which need more intensive effort.

It is not the purpose of the committee, in this set of hearings, to draw any moral, political, or philosophical conclusions; nor to get into other associated fields, such as disarmament. Nor is it our purpose at this time to cover in detail the question of hazards in connection with nuclear powerplants, or the matter of workmen's compensation for employee radiation hazards. These subjects might more appropriately be taken up in a subsequent series of hearings.

[Hrg. JCAE
The Nature of Radioactive
Fallout and its Effects on Man
Pt 1
1957, 85th Congress
1st Session
[Here after referred to as:
Hearings JCAE
Radioact. Fallout
1957.]

who has been exposed to a degree of radiation probably greater than any person that we know. He has told us the consequences to him of his own body. Since radiation exposure has been said to involve a question of sterility and so forth, unless he would rather not answer, I would like to give him the opportunity of indicating.

Dr. GRAVES. I had one daughter before the accident. I have had a daughter and son since the accident. The daughter and son as far as can be told are perfectly normal kids. We love them very much.

Representative VAN ZANDT. From a heredity standpoint, do they show any extraordinary amount of energy as a result of your brush with atomic energy?

Dr. GRAVES. Speaking as a parent they are very intelligent children.

Representative HOLIFIELD. Thank you very much. Our next witness is Dr. W. W. Kellogg of the Rand Corp. and he will speak to us on the subject of atmospheric transport, storage, and removal of particulate radioactivity.

Dr. Kellogg, how long is your presentation?

STATEMENT OF DR. W. W. KELLOGG, RAND CORP.*

Dr. KELLOGG. I have a report for the record which is somewhat long, and I was not planning to give it all now. It has a lot of documentation in it. I was going to abstract it to the committee orally. I could do it in 30 or 40 minutes. Is it too late to do that?

Representative HOLIFIELD. We will accept your prepared statement for the record. We will be glad to have you summarize it.

(The statement referred to follows:)

ATMOSPHERIC TRANSPORT AND CLOSE-IN FALLOUT OF RADIOACTIVE DEBRIS FROM ATOMIC EXPLOSIONS

(By Dr. William W. Kellogg, RAND Corporation)

INTRODUCTION

It is well known that the radioactive debris from an atomic explosion is carried high into the atmosphere, and that eventually all of it reaches the ground. However, there are a variety of things which can happen to these particles on their way to ground, and their paths can be quite complicated. The purpose of the present report is to describe and document part of this process of radioactive fallout.

In order to limit the discussion, fallout here will be taken to mean "close-in fallout," the fallout which occurs during the first day or two following the explosion, and which deposits radioactivity within a few hundred miles of ground

* Born: February 14, 1917, at New York Mills, N. Y. Educated: Brooks School, North Andover, Mass.; Yale University, bachelor of arts, 1939; University of California, Berkeley, graduate studies in physics; UCLA, master of arts in meteorology, 1942; UCLA, doctor of philosophy in meteorology, 1949. Occupations: Prep school science teacher (Brooks), 1939–40; teaching assistant, physics, University of California, 1940–41; U. S. Air Force pilot weather officer, separated with rank of captain, 1941–46; research assistant, research associate, and assistant professor (in succession), Institute of Geophysics, UCLA, 1946–52; research scientist, the Rand Corp., Santa Monica, 1947–present. Affiliations: American Meteorological Society (committee on admissions, upper atomsphere committee); American Geophysical Union (upper atmosphere committee); Society of Sigma Xi; member, meteorological committee on the biological effects of atomic radiation, National Academy of Sciences-National Research Council; member, working group in internal instrumentation of the earth satelite program; member, ad hoc panel for measuring radioactivity in air of the United States National Committee for the International Geophysical Year; formerly member, upper atmosphere committee, NACA (now defunct). (Submitted by Witness.)

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Radioact. Fallout
1957, Pt I

ro. The intermediate scale of fallout (that which occurs in the first few eks) and the worldwide fallout will be treated by others.

Although the purpose is to tell what we know about fallout, an effort will o be made to point out the areas of uncertainty in our knowledge. Fallout a process which is affected by many different things, and the atmosphere by very nature behaves in an erratic and random way. Thus, it is fair to say the outset that, no matter how well we could document our observations of llout, there would still be an area of uncertainty due to the randomness of process. This aspect should be borne in mind in considering the evidence ich follows.

DESCRIPTION OF THE PROCESS OF CLOSE-IN FALLOUT

There is a fundamental difference between the fallout from an atomic device tonated at the ground and the fallout from one detonated so high that the eball does not touch the ground. In the case of the surface burst, large quantis of surface material are broken up, melted, and even vaporized, and some of is material comes in intimate contact with the radioactive fission products. ien, after the atomic cloud has stopped rising and the violent updrafts assoated with the explosion have subsided, the larger and heavier particles start lling back to the ground. The result is an area around ground zero and extendg downwind which is covered in a more or less systematic way with particles ntaminated by atomic debris.

In the case of an air burst in which the white-hot fireball never reaches the urface, the radioactive fission products never come into close contact with the urface material; they remain as an exceedingly fine aerosol. At first sight this ight be thought to be an oversimplification, since there have been many cases which the fireball never touched the ground, but the surface material was bserved to have been sucked up into the rising atomic cloud. Actually, however, in such cases a survey of the area has shown that there has been a negligible mount of radioactive fallout on the ground. Though tons of sand and dust may ave been raised by the explosion, they apparently did not become contaminated y fission products.

The explanation for this curious fact prabably lies in a detailed consideration f the way in which the surface material is sucked up into the fireball of an air urst. Within a few seconds from burst time, the circulation in the atomic fireball develops a toroidal form, with an updraft in the middle and downdraft around the outside. Most of the fission products are then confined to a doughnut-shaped region, and may be thought of as constituting a smoke ring. When the surface debris is carried into the fireball a few seconds after the detonation, it passes up along the axis of the cloud, through the middle, and can often be seen to cascade back down around the outside of the cloud. In its passage through the cloud, it has passed around the radioactive smoke ring but has never mixed with it.[1]

There has not been a large number of surface shots in the United States test series, and most of these have been set off in the Pacific area, where complete documentation of the fallout has been difficult because the greater part of the material came down in the open ocean or in the water of the lagoons. During the last Pacific test, however, a method of surveying the ocean to determine the distribution of the fallout was used which has given us some fairly complete and quantitative data on the pattern of the fallout from some larger yield devices.[2] A reanalysis of the fraction of the debris which came down within the first few hundred miles from the various Operation Redwing surface shots by Tucker,[3] based on the ocean and atoll survey made jointly by the Scripps Institute of Oceanography, the Naval Radiological Defense Laboratory, the Evans Signal Laboratory, the New York Operations Office of the AEC, the Chemical Warfare Laboratories of the Army Chemical Center, and the Air Forces Special Weapons Center, reveals that from a large yield surface burst about 85 percent falls down in roughly the first 24 hours; for a barge shot in the water of a lagoon the fraction is between 65 and 70 percent. According to Tucker, the accuracy of the estimates

[1] Kellogg, W. W., R. R. Rapp, and S. M. Greenfield: Close-In Fallout, Jour. Met., vol. 14, No. 1, pp. 1–8, 1957.
[2] Van Lint, V. A. J., L. E. Killion, J. A. Chiment, and D. C. Campbell: Fallout Studies During Operation Redwing, Field Command, AFSWP, Operation Redwing Preliminary Report, ITR-1354, October 1956 (Secret, R. D.).
[3] Tucker, B. L.: Fraction of Redwing Radioactivity in Local Fallout, RAND Corp., Report in preparation, May 1957 (Secret, R. D.).

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

here is probably no better than 20 or 30 percent, so the good agreement which he obtained for various kinds of shots may be fortuitous.[4]

The one other piece of evidence on the fraction falling out from a surface shot comes from Operation Jangle. The Los Alamos Health and Safety Division had a number of stations downwind to record the fallout, and the Air Force surveyed a larger area by flying an instrumented aircraft at low altitudes over the desert. Two analyses have been made of the resulting fallout pattern in order to estimate the fraction of the debris which was represented, one by Lulejian[5] and the other by Rapp.[6] The results are as follows:

	Percent
Lulejian: Beyond 10 miles from ground zero and within 200 miles	60±2
Rapp: Beyond 4 miles from ground zero and within 200 miles	7[illegible]
Rapp: Total fallout out to 200 miles	87

It should be noted that the famous March 1, 1954, test of the Castle series in the Pacific, which received some publicity because of the fallout on some nearby inhabited atolls,[7] was not well enough documented to enable one to get a good estimate of the percentage of fallout. In order for such an estimate to be made it is clearly necessary to be able to lay out the *complete* fallout pattern. This was not possible here, since the islands on which the fallout occurred occupied only a part of the pattern, and were probably not in the region of maximum fallout. This event will be discussed more below.

As pointed out above, if the height of burst is raised, the amount of surface material which can become intimately mixed with the fission products becomes less. As a result, the fraction which takes part in close-in fallout decreases with increasing height of burst. A tower shot does not exactly follow this trend however, since the material in the tower itself and in the cab at the top of the tower apparently provides some radioactive fallout. The fraction falling out from a tower shot appears to be quite variable, as can be seen from the following tabulation prepared by Kenneth Nagler and Dr. Lester Machta of the United States Weather Bureau, based on a detailed analysis of the actual fallout from a number of tests in Nevada, all of which had yields in the range of 12 to 18 kt.

	Percent
300-foot tower	17[illegible]
	12[illegible]
	8[illegible]
	7[illegible]
	7[illegible]
Average	10[illegible]
500-foot tower	5.4
524-foot airburst (especially uncertain)	1[illegible]

It should be noted that the particular airburst cited here produced a fireball which almost touched the ground. Higher airbursts, as mentioned above, produce no significant close-in fallout.

So far the discussion has been concerned with *the total amount* of radioactive material taking part in the fallout. The *distribution* of this material on the ground depends on a number of parameters—wind structure, yield and height of burst, and kind of surface. The yield and height of burst predominantly determine the distribution of radioactivity with size of particle, and the height and size of the cloud at time of stabilization. The kind of soil taken into the fireball presumably has an effect on the particle size distribution too. In order to make a calculation of where the debris will go, all these factors must be taken into account in one way or another. The various ways of handling this complicated situation are treated in the next section.

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[4] In ref. 2, Appendix E, similar estimates are made which are less than the ones quoted. However, it appears that a different "normalization factor" was used to convert from kt yield to megacurries of fission product activity at one hour, and this was combined with an inappropriate decay rate to convert from the time of observation to the *reference time* of 1 hour. Further, Tucked introduced a correction for the radioactive sodium from the ocean water which was activated by neutrons from the explosion, and which contributed to the observed radioactivity.

[5] Lulejian, N. M.: Radioactive Fallout from Atomic Bombs, Air Research and Development Command, C3-36417 (with supplement), November 1953 (Secret, R. D.).

[6] Greenfield, S. M., W. W. Kellogg, F. J. Krieger, and R. R. Rapp: Transport and Early Deposition of Radioactive Debris from Atomic Explosions, Report of Project Aureole, Rand Corp., R-265-AEC, July 1954 (Secret, R. D.). See chapter 4.

[7] Cronkite, E. P., V. P. Bond, and C. L. Dunham: Some Effects of Ionizing Radiation on Human Beings, United States Atomic Energy Commission, July 1956.

Before proceeding further it might be well to mention something about what happens to these radioactive particles after they are on the ground. The largest particles involved may be a millimeter or more in diameter, but these constitute only a small fraction of the total debris. Both observation of the particles, collected in many ways in the Pacific and in Nevada, and theoretical calculations of the way in which they must fall indicated that the majority of the particles taking part in the close-in fallout have diameters between about 50 and 400 microns (1 micron is 10,000 cm.).[8 9 10 11] According to G. R. Hilst, of the Hanford Atomic Products Operation, particles of less and about 50 microns diameter are difficult to erode by wind action because they tend to sift down and cling between the larger particles of the soil, and particles larger than about 500 microns diameter are difficult to erode because the wind cannot easily lift them. The particle size range in which radioactive fallout lies is the size which can be most easily lifted by the wind and redeposited somewhere else. Under high wind conditions this could further complicate the prediction of where the debris would go.

COMPUTING FALLOUT PATTERNS

Clearly, the direction that a particle takes on its way to the ground is determined by the wind. It is not the wind at one level alone which must be considered, but the cumulative effect of all the winds between the ground and the initial altitude of the particle. There have been a number of mehods developed to make some sort of best guess about where the debris will be deposited, and these all have one element in common: The wind field from the ground up to the atomic cloud must be analyzed and integrated.

In order to understand the matter of fallout computation, it is necessary to see what is involved in an integration of the wind field. Figure 1 shows, in schematic form, how such an integration can be done vectorially. Let it be assumed for the moment that a particle starting from 50,000 feet, for example, has a constant rate of fall. In such a case it will spend the same amount of time in each layer of a given thickness, say 5,000 feet. The direction of its travel while in a given layer will be in the direction of the mean wind in that layer, and the distance it travels while in the layer will be proportional to the length of the corresponding wind vector. Then it falls down into the next layer and again travels with the mean wind in that layer. In order to determine the total distance and direction which this particle traveled on the way to the ground it is only necessary to add the successive wind vectors for each layer head to tail, and the resultant vector will represent the total travel.

In practice, meteorologists have found it convenient to add the vectors starting from the ground and working upward, as shown in figure 1b. Now the integrated wind, or total particle travel, from any given altitude can be immediately determined by drawing a vector from the origin to the head of the arrow corresponding to the correct altitude. In other words, a family of integrated winds can be produced in this way, and the direction and rate of travel of all particles can be estimated by inspection of the diagram. Recall that it was assumed here that the particles fell at a constant rate. This is not the case in actuality, and so the simple vector addition described here must be modified in the more sophisticated analyses of fallout.

There have been four main approaches to the construction of a fallout analysis, depending on the amount of time available for the computation and the degree of completeness required. It should be emphasized that these various approaches do not compete with each other, since they are each tailored to answer a different set of questions about the fallout, and they differ greatly in the amount of labor required to carry them out. In order of increasing complexity, they are—

[8] Rainey, C. T., J. W. Neel, H. M. Mork, and Kermit H. Larson: Distribution and Characteristics of Fall-Out at Distances Greater than 10 Miles from Ground Zero, March and April 1953, U. C. L. A. School of Medicine, Operation Upshot-Knothole, WT-811, February 1954 (Secret, R. D.).

[9] Heidt, W. B., Jr., E. A. Schuert, W. W. Perkins, and R. L. Stetson: Nature, Intensity, and Distribution of Fallout from Mike Shot, U. S. Naval Radiological Defense Lab., Operation Ivy, WT-615, November 1952 (Secret, R. D.).

[10] Stetson, R. L., E. A. Schuert, W. W. Perkins, T. H. Shirasawa, and H. K. Chan: Distribution and Intensity of Fallout, U. S. Naval Radiological Defense Lab., Opertaion Castle, WT-915, January 1956 (Secret, R. D.).

[11] Wilsey, E. F., R. J. French, and H. I. West, Jr.: Fallout Studies, Army Chemical Center, Operation Castle, WT-916, February 1956 (Secret, R. D.).

Hearings JCAE
Radioact. Fallout
1957, 74.1

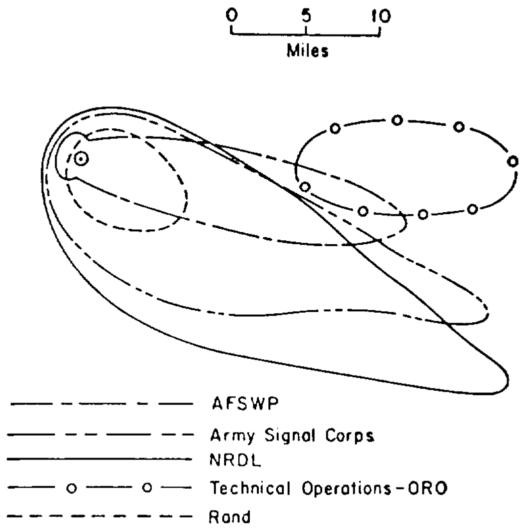


FIGURE 3.—AFSWP comparison of fallout computations (Ref. 18) cases for "Condition B," 1 megaton yield, showing contours for 1,500 r dose accumulated by 48 hours.

TABLE 2.—*Condition B—Gradual shear of approximately 90°*

Washington, D. C. (Siver Hill)—38°50′ N., 76°57′W.—0300 Grenwich mean time—Sept. 28, 1952—Elevation: 289 feet]

Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)	Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)
Surface	Calm	0	45,000	292	23
[illegible]	358	11	50,000	290	28
[illegible]	009	20	55,000	290	20
[illegible]	325	14	60,000	268	11
[illegible]	282	19	65,000	276	21
[illegible]	263	34	70,000	293	7
[illegible]	263	47	75,000	293	8
[illegible]	273	37	80,000	285	10
[illegible]	308	27	85,000	250	11

The significant thing to note is the discouragingly poor agreement between the various results. It is possible that some of the agencies have modified their models in the past 2 years, and that there would be better agreement if the exercise were repeated now, but it is highly unlikely that the agreement would be anywhere nearly exact. It would seem that we simply do not know enough yet about the process of fallout to be able to reconstruct a fallout model (no matter how sophisticated in conception) on which everyone would agree.

PREDICTION AND RECONSTRUCTION OF FALLOUT PATTERNS

As stated in the previous section, there have been a number of methods developed for the computation of fallout patterns. Naturally, these were developed with the observed fallout from a handful of surface and tower bursts in hand, and all claim (to a greater or lesser degree) to give results which agree with reality.

The real question of agreement with reality is, however, obscured by the fact that reality is hard to define, even in retrospect, when all the facts are collected. First, the wind field is poorly observed, and the variations in the wind field with time and space are difficult to take into account in reconstructing what

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

happened. The meteorological literature has a number of studies of this variability and of the uncertainties in observation,[20 21 22] A good rule of thumb, derived from experience with the tracking of constant-level balloons, is that, given a good upper air network of the sort which covers the United States, the path of a particle cannot be determined from an analysis of the wind field to better than 20 percent of the length of the trajectory. Thus, after going 100 miles, the uncertainty in the position of a drifting particle is about 20 miles, even when we have all the upper-air data which we can lay our hands on.

Furthermore, the fallout itself is poorly observed, due to the great distances that have to be covered, the irregularities of the terrain (in Nevada) or the uncertainty of where it went after landing in the ocean (in the Pacific). Thus, even if our computation were, in principle, a perfect one, we would still not have a clear picture against which to compare it.

When the meteorologist is faced with the problem of *predicting* a fallout pattern, the uncertainties of a wind prediction are added to the uncertainties in the computational model. The longer the time lag between prediction and the event, the greater will be the uncertainties.[23] For times of up to 12 hours, it appears that persistence is about as good as a forecast, and after about 2 to 3 days a forecast is not much better than a climatological mean.

Without belaboring this point, it should suffice to show two interesting examples of predicted and reconstructed fallout patterns. One is from a burst of roughly 30 kilotons on a tower in Nevada, the Open or Civil Defense shot of May 5, 1955. The patterns shown in figures 4 and 5 were prepared by Kenneth Nagler of the United States Weather Bureau, and show the patterns which were predicted 2 hours before shot time by 2 methods of models. The two models, one of the Weather Bureau and the other of the Los Alamos Scientific Laboratory and the University of California Radiation Laboratory, were used. The first involved a hand computation by an elaborate graphical analysis, the other involved a high speed digital computer (IBM–701). There were some differences in the two models, but these were not basic ones—that is, they both used the general approach described in the previous section. It will be noted that both methods predicted patterns extending due north from the shot point, following the direction of the H-2 hour predicted wind. The observed pattern, shown in figure 6, was reconstructed from the available road monitoring and from a few aircraft measurements by Nagler. The fallout started out northward, and then curved to the eastward, reflecting a gradual shift in the wind direction from south to west that took place in the hours following the shot. Also shown in figure 6 is an attempt to reconstruct the pattern, using the Weather Bureau's model and taking into account the change of wind with time and space. The result agrees with the obesrved pattern better, but still not perfectly.

Another example of a fallout pattern which changed its direction during the later stages of the fallout is the March 1, 1954, Castle shot on the Bikini atoll, referred to earlier. In this case, the fallout apparently started out in a direction east-northeast, but a continued veering of the wind caused it to curve more to the east and east-southeast, until one side of it lay across some neighboring atolls. A study of this event by Rand in which the fallout was computed with the shot-time wind alone, and then again with the variable (true) wind, shows clearly how the pattern must have curved as it progressed.[24]

It is interesting to note that both of these examples demonstrate the effect of the changing wind with time, an effect which is often very hard for the meterologist to specify. A study of the statistics of this change of wind with time has been made by Frank Cuff, department of meteorology, University of Utah.[25] Referring to the integrated wind (see above) from the ground up to various altitudes in Nevada, he found the mean absolute bearing changes shown in table 3.

[20] Neiburger, N., L. Sherman, W. W. Kellogg, and A. F. Gustafson: On the Computation of Wind from Pressure Data, Jour. Met., vol. 5, No. 3, pp. 87–92, 1948.
[21] Rapp, R. R.: The Effect of Variability and Instrumental Error on Measurements in the Free Atmosphere, New York University Meteorological Papers, vol. 2, No. 1, June 1952.
[22] Kochanski, A. B.: Wind, Temperature, and Their Variabilities to 120,000 Feet, Air Weather Service Technical Report, 105–142, May 1956.
[23] Ellsaesser, H. W.: Errors in Upper-Level Wind Forecasts, Air Weather Service Technical Report, 105–140/1, December 1956.
[24] Greenfield, S. M., and R. R. Rapp: Fallout Computations and Castle-Bravo—A Case Study, Rand Corp., RM–1855, January 1957 (secret, R. D.).
[25] Cuff, R. D.: A Study of the Time Variability of Integrated Winds Near Las Vegas, Nevada, thesis for M. S. Degree, Dept. of Meteorology, Univ. of Utah, March 1957.

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

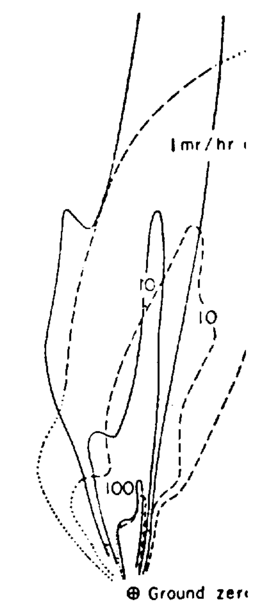


FIGURE 4.—The observed fallout
puted by the Weather Burea
1955.

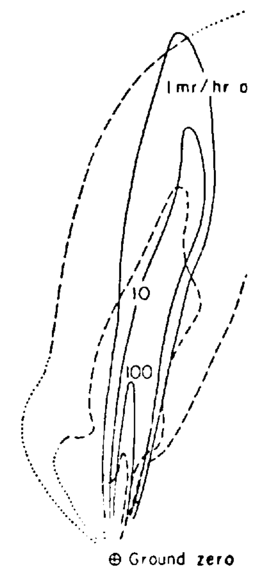


FIGURE 5.—The observed fallout
puted by LASL–UCRL using

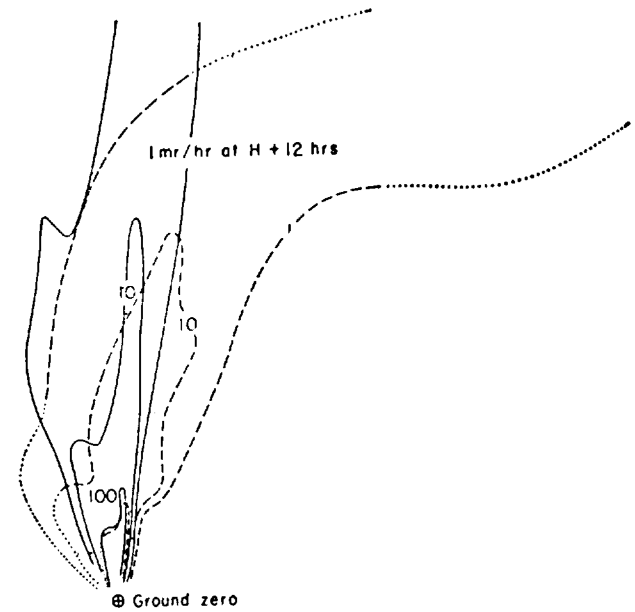


FIGURE 4.—The observed fallout distribution (dashed lines) and the pattern computed by the Weather Bureau using winds predicted at H–2 hours. May 5, 1955.

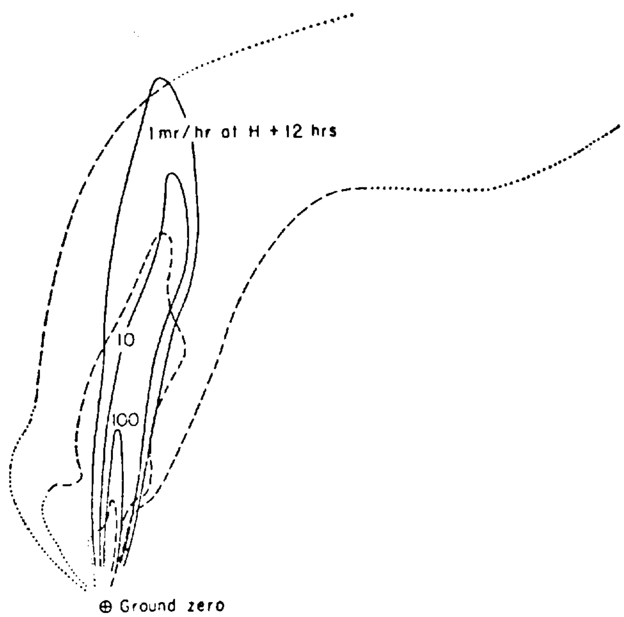


FIGURE 5.—The observed fallout distribution (dashed lines) and the pattern computed by LASL–UCRL using winds predicted at H–2 hours. May 5, 1955.

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

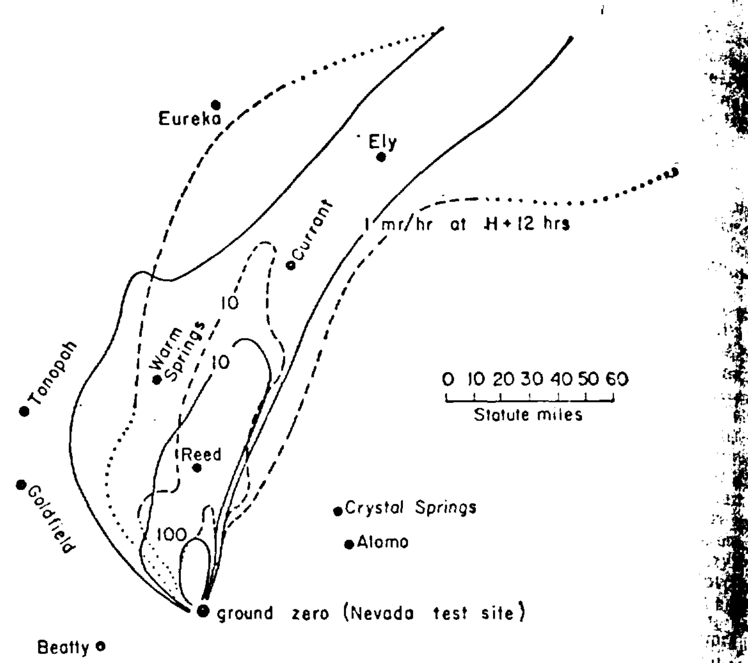


FIGURE 6.—The observed fallout distribution (dashed lines) and the pattern reconstructed by the Weather Bureau using a hand computation with time and space variation of winds (solid lines). May 5, 1955.

TABLE 3.—*Mean absolute bearing change of integrated winds*

Time interval (hours)	Integrated wind from surface to—		
	20,000 feet	40,000 feet	50,000 feet
3	12°	7°	6°
6	[illegible]	15°	13°
12	[illegible]	28°	----------

It will be noted that the bigger the thickness of the atmosphere considered in forming the integrated wind the smaller is the shift of the wind. This probably reflects the fact that wind shifts at one level may sometimes be partially canceled by opposite wind changes at another altitude. Another lesson to be learned from this study is that the statistics of the wind at one level cannot be relied upon to give reliable information about the statistics of the integrated wind, which must combine the effects at many levels.

A recent study of the predictability of fallout for the Nevada test site has been made by Jack Reed of the Sandia Corp.[26] Here the variability of the wind, the forecasting accuracy, the length of the forecast period, etc., are all considered in order to given an estimate of the degree of confidence with which the fallout can be put into an uninhabited "safe sector." This approach to the problem is one which should be taken more often in meteorology, since it demonstrates that any weather forecast should have a probability assigned to it—a probability which is always less than one.

THE DYNAMICS OF FALLOUT

So far a great deal has been said about the final fallout pattern and how it is computed. A very important feature of the pattern from a practical standpoint

[26] Reed, J. W.: Estimating Safety Probabilities From Fallout Forecasts for Nevada Test Site, Sandi Corp. report SC-1073 (TR), February 1957.

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

TUESDAY, MAY 28, 1957

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION OF THE
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C.

The special subcommittee met, pursuant to recess, at 10:05 a. m., in room 457, Senate Office Building, Hon. Chet Holifield, chairman of the subcommttee, presiding.

Present: Representatives Holifield, Durham (chairman of the Joint Committee), Price, Dempsey, Van Zandt; Senators Pastore, Hickenlooper, and Bricker.

Present also: Professional staff members James T. Ramey, executive director; George E. Brown, Jr., Hal Hollister, staff technical adviser, and Paul Tompkins, consultant.

Representative HOLIFIELD. The committee will be in order.

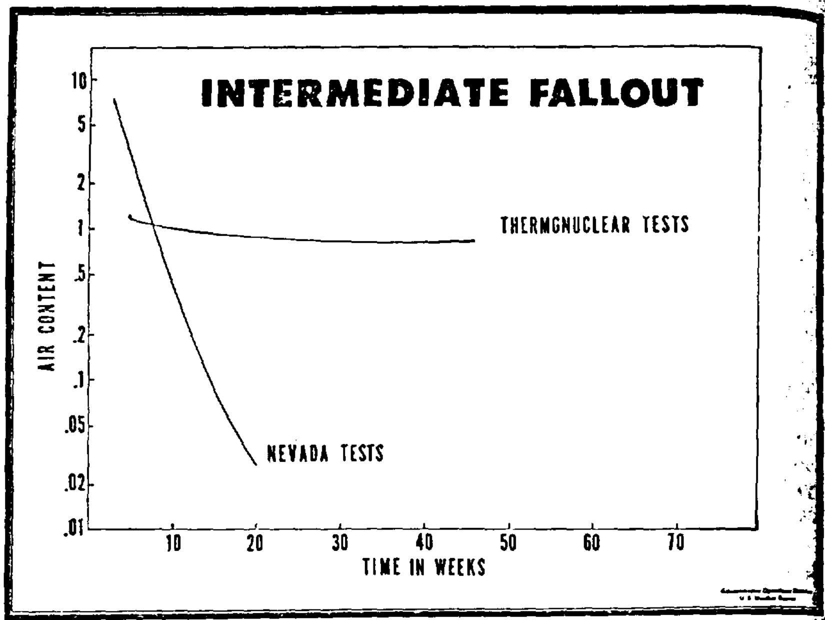
Today we open our second day of the hearings on the nature of radioactive fallout and its effect on man. Yesterday we began our hearings with an introductory statement by Dr. Charles L. Dunham, Director of the Division of Biology and Medicine of the Atomic Energy Commission, in which he provided some perspective on the general radiation problem as a basis for the beginning of the hearings. He was followed by Dr. Mark Mills, associate director of the Livermore Laboratory of the University of California, who provided us with technical background information on radioactivity and radiation and the hazard aspects of controlled fusion and fission reactions.

Yesterday afternoon, Dr. Alvin C. Graves, chief of the testing operations of the Los Alamos Scientific Laboratory, provided more detailed information on the production of radiation and radioactivity by the detonation of nuclear weapons. He described the effects of immediate bomb detonations, together with local fallout and worldwide fallout. He also gave some indications of the nature of the fallout from so-called clean and dirty weapons.

Dr. Graves was followed by Dr. Frank Shelton, of the Armed Forces special-weapons project, and Gen. Alfred D. Starbird, Director of the AEC Division of Military Applications, who provided a few comments on Dr. Graves' testimony and the new book, The Effects of Nuclear Weapons.

Incidentally, General Starbird indicated that the printed statement entitled "Testimony Before the Joint Committee on Atomic Energy on the Production of Radiation and Radioactivity From Nuclear Weapons—Topic V" was his statement, which he submitted for the record. The chariman and committee were under the impression that

FIGURE 2



The next placard (2) shows the decrease with time of the atmospheric radioactivity from tropospheric and stratospheric sources. We see that for a Nevada A-bomb-type shot, in which air content is plotted against time in weeks after the explosion, the atmospheric radioactivity decreases rapidly with time after the test, so that within a matter of weeks, or at most a few months, the level of radioactivity is not appreciably above natural backgrounds. Precipitation and turbulence quickly remove the particles from the atmosphere. On the other hand, from the large-scale explosions, the thermonuclear tests, which throw their debris into the stratosphere, one finds practically no change with time. Although the same processes of removal are still active in the troposphere, the curve fails to show the decrease because there is a continual feeding of new radioactive debris from the stratosphere downward.

TROPOSPHERIC FALLOUT

Let us first look at the fallout from tropospheric debris. This placard (3) shows isolines of deposition from one of the Nevada test series. It is a Mercator map of the entire world, and the very heavy shading indicates the area around Nevada.

The brightness of the red coloring is proportional to the amount of fallout. I use the word "tropospheric" and "intermediate" interchangeably in this discussion. This picture illustrates the prevailing west-east flow by the fact that most of the radioactivity lies in the same belt of latitude as the original latitude of the explosion. The fallout is carried primarily to the east by the prevailing winds, and decreases in intensity as we get farther from the test site.

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

FIGURE 3

Hearings JCAE
Radioact. Fallout
1957, 741

Representative HOLIFIELD. Before we leave that, Dr. Machta, I want to reread one of the lines you have given.

Dr. MACHTA. Yes, sir.

Representative HOLIFIELD (reading):

This picture illustrates the prevailing west-east flow by the fact that most of the radioactivity lies in the same belt of latitude as the original latitude of the explosion.

Judging from the shading on your map there, and from this statement, then, there is a deposition in the Temperate Zone, assuming that is where these tests occur, where most of the people live, which is higher in intensity, although in different gradations, than it would be in either of the polar zones?

Dr. MACHTA. That is exactly correct, sir.

Representative HOLIFIELD. So when we talk about average global fallout, although it is a theoretical equation, it is an unreal evaluation in terms of the phenomena which actually occur?

Dr. MACHTA. I would like to take this up later. My main presentation actually deals with the nonuniformity of the fallout, and this is one of the aspects which gives rise to nonuniformity, namely, that the tropospheric fallout remains in the same latitude belt that the explosion takes place. But this is only one of the aspects.

Representative HOLIFIELD. My observation is, although it is only one of the aspects—my observation still is——

Dr. MACHTA. Is correct.

Representative HOLIFIELD. Is correct?

Dr. MACHTA. Yes, sir.

Representative HOLIFIELD. Thank you.

Dr. MACHTA. The next placard (4) provides the tropospheric fallout, the cumulative deposition for the first 35 days from the Castle-Bravo, the March 1, 1954, thermonuclear detonation in the Marshall Islands, showing once again that the fallout lies largely in the belt of latitude in which the explosion takes place. In the case of the large explosions, it is likely that the stem of the nuclear cloud provides most of the radioactive fallout in this period.

What fraction of the radioactive debris is deposited in the first few weeks or months—aside from the local fallout? For the typical Nevada tower shot, perhaps 75 percent, and for the high-yield ground explosion in the Pacific Proving Grounds, somewhere between 1 and 5 percent. These figures are very uncertain. Thus for the high-yield explosions, the delayed fallout is more important than the tropospheric fallout. This is because about 80 percent falls out locally, and when we add to this 5 percent more, we still have of the order of 15 to 20 percent, on the average, in stratospheric fallout that is still left after local and tropospheric fallout has ceased.

Thus, for the high-yield explosions, the delayed fallout is more important than the tropospheric fallout. It is evident that the tropospheric fallout is not uniform over the globe, as you just pointed out, sir.

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

STRATOSPHERIC FALLOUT

Finally, those particles which do not fall out locally or in the first 1 or 2 months, remain suspended in the atmosphere for a prolonged period—a matter of years, on the average. This has been termed

FIGURE 4

Hearings JCAE
Radioact Fallout
1957, Pt 1

Your article on World Wide Travel of Atomic Energy Debris will be inserted at this point.

[Reprinted from Science, September 14, 1956, vol. 124]

World-Wide Travel of Atomic Debris

L. Machta, R. J. List, L. F. F. Hubert[1]

For centuries meteorologists have thought of exploring large-scale atmospheric circulations by means of tracers. The literature describes how man has successfully tracked fluorescent particles to a distance of 100 miles,[2] used radioactive tracers across the United States,[3] and followed volcanic ash and forest fire smoke over distances of the order of 1000 miles.[4] Only the dust from a major volcanic eruption, such as Krakatao, has been tracked on a truly global scale.

During two of the nuclear test periods in the Pacific Proving Grounds of the U. S. Atomic Energy Commission, sufficient radioactive debris was thrown into the atmosphere to be deposited in both hemispheres. Measurements of the deposited radioactivity were obtained from exposed sheets of gummed film. The details of the network and the sampling and measurement techniques have been described by Eisenbud and Harley.[5] It should be noted, however, that the deposition of particles on the adhesive surface depends either on the presence of precipitation or, in dry weather, on turbulence to assist the impaction of the particles on the horizontal surface of the paper. It is thus possible to have a cloud of radioactive particles pass two stations simultaneously and have only the station with rain note the presence of the particles overhead. The gummed-film method of collection is recognized as being as crude as it is simple.

The nuclear explosions are treated in this article, the Mike shot on 1 November 1952 and the Bravo shot on 1 March 1954. The shots were similar in that both are described as having had energy in the megaton range, both were detonated at or near the earth's surface on a coral island, and both had atomic clouds that penetrated into the stratosphere. To the meteorologist, the main difference of interest between the two events is the season.

WINDS

The winds acting on the two atomic clouds at the time of detonation are illustrated in Fig. 1. The wind structure has been estimated, when necessary, from observations at nearby locations and times. On both days the tropopause was found at an altitude of about 55,000 feet, and it separated winds blowing from different directions. The easterly winds above the tropopause increased in speed to the highest altitude of the available wind information for the Bravo shot, while for Mike the easterly winds decreased in speed and ultimately changed to westerly winds. The easterly winds in the trade-wind layer, the moist maritime air mass lying near the sea, extended up to about 20,000 feet during the detonation of the Mike device, while for the Bravo shot they were below 10,000 feet. Between the trade-wind layer and the tropopause, one normally finds westerly winds. During the Mike shot these westerlies were temporarily interrupted and became southerly winds, while for the Bravo shot they were toward a more normal bearing.

In Fig. 2 is found the approximate area covered during the early days by that part of the nuclear cloud from the Mike shot which was located below the tropopause. The shaded areas in Fig. 2 have been deduced from meteorological considerations alone, and, in many cases, are subject to considerable uncertainty. Shading was discontinued when the meteorological data no longer warranted any reasonable estimate of the path. The light winds and sparsity of upper-wind observations have made tracing the upper tropospheric portion of the Mike cloud

[1] The authors are on the staff on the U. S. Weather Bureau, Washington, D. C.
[2] R. R. Braham, B. K. Seely, W. D. Crozier, Trans. Am. Geophys. Union 33, 825 (1952).
[3] R. J. List, Bull. Am. Meteorol. Soc. 35, 315 (1954).
[4] H. Wexler, Weatcherwise 3, 129 (1950).
[5] M. Eisenbud and J. H. Harley, Science 124, 251 (1956).

Hearings JCAE
Radioact. Fallout
1957, Pt 1

particularly uncertain. For this reason, the time of passage across the North American mainland is unknown. Tracing was discontinued on 7 November. The tradewind portion of the nuclear cloud appears to have split south of Japan, the upper portion *(near 20,000 feet) curving* around a Pacific high cell and entering the United States about 9 November.

The estimated meteorological path of the Bravo cloud is shown in Fig. 3. The upper tropospheric portion of the nuclear cloud was traced to the Central American area by about 5 March, and an offshoot extending northward into the United States at about 20,000 feet was detected approximately 1 week later.

Differences between the paths of the Mike and Bravo clouds are evident from Figs. 2 and 3. In part, the differences are seasonal and in part due to the specific meteorology for the shot days. Thus, in November the mid-tropospheric westerly winds are not as strong as they are in March, and they are located farther north, on the average. Further, in November one finds an anticyclonic circulation not far from the Marshall Islands which is not typically present in March. The shallowness of the trade-wind layer during the Bravo shot is an example of a feature *unusual for the region during any season.*

There has been no attempt to track the stratospheric portions of the atomic cloud because of the sparsity of wind observations at these altitudes. Evidence from numerous isolated high-level winds, not necessarily obtained during the periods of the two nuclear tests, suggests a path that would travel around the earth at about the same latitude as the point of origin. It is interesting to note that in no case was it imperative to rely on stratospheric transport of the nuclear debris to account for the earliest arrival at any point, for the transport of the nuclear cloud in the troposphere appeared to account for the first observations of radioactivity.

An attempt to determine the earliest arrival time at the ground at each point of observation has been undertaken. The results, which are shown in Figs. 2 and 3 as the number of days after the shot day, should in many cases be viewed with caution. First, in many of the stations in the Southern Hemisphere, the deposited activity was so low that it made the arrival date almost meaningless. Second, despite elaborate precautions, it is likely that some gummed films were contaminated during handling. Finally, as noted in the second paragraph the apparent arrival time of the cloud at many stations coincided with rainfall, suggesting that the nuclear cloud may have been overhead some time earlier but that precipitation *was required to bring its activity to earth.*

FALLOUT

It is noted that, in accordance with the meteorological estimates, the fallout over the United States progressed roughly from west to east during the Mike shot. Fallout from the Bravo event did not appear at the West Coast stations in the United States until 2 weeks after one of the cloud protuberances entered the central United States. Of perhaps greatest interest, although also of greatest doubt, are the comparatively early arrival times in the Southern Hemisphere. Thus, for example, a literal interpretation of the chart reveals that every station in the Southern Hemisphere showed an earlier arrival time than did the United States West Coast stations for the Bravo case. Also of interest are the comparatively late arrival *times for the mid-Pacific stations west of the Hawaiian* Islands during the Mike fallout. These stations were south of one branch of the nuclear cloud and north of the other.

Hearings JCAE
Radioact. Fallout
1957, Pt 1

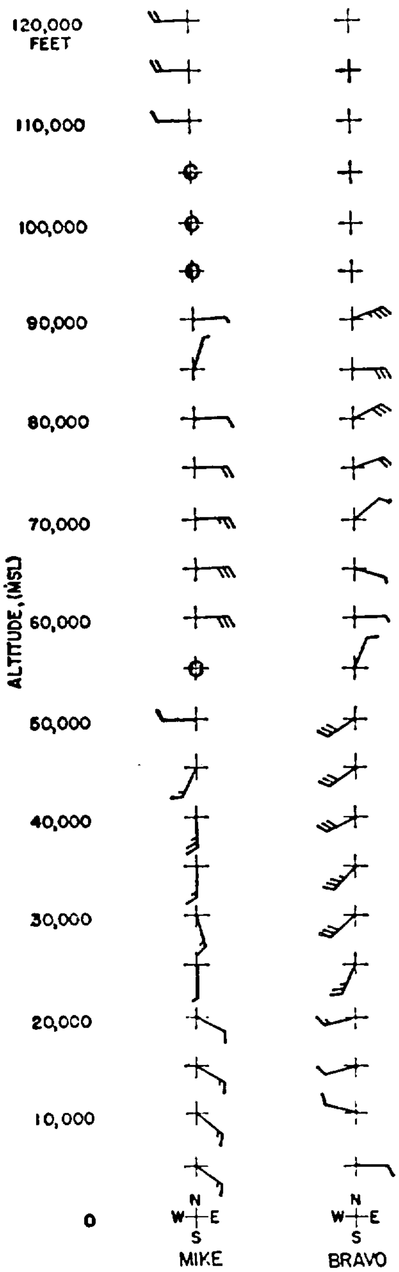


FIGURE 1.—Upper winds at shot time. Arrows blow with the winds, and barbs indicate wind speed; full barb, 10 knots; one-half barb, 5 knots.

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

The actual fallout at each stat
Figs. 4 and 5. The units are cu
days following each event and a
100 square miles (the values ha
gummed film.) Several features
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for the Mike shot, as opposed to
shot. Second, the isolines locat
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tional evidence.

It is apparent that radioactive
possess all the desired attributes
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effective sampling program for
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greater value from future tests
tions at other locations and time

The actual fallout at each station and an analysis of the data are shown on Figs. 4 and 5. The units are cumulative decayed beta activity for the first 35 days following each event and are approximately equivalent to millicuries per 100 square miles (the values have not been corrected for the efficiency of the gummed film.) Several features that differentiate the two maps should be noted. First, an average value for all United States and Canadian stations was obtained for the Mike shot, as opposed to values for individual stations during the Bravo shot. Second, the isolines located between points on the West Coast of the United States and points in the Western Pacific Ocean are also based on fallout observations obtained from transport vessels for Bravo. Finally, as is evident, the network was expanded between the two events, primarily in an attempt to locate stations in rainy areas. In many cases, when the period of record is incomplete or the data are suspect, parentheses have been placed around the number. No attempt has been made to reconstruct the isolines for the fallout that occurred within the first 24 hours of the shot.

The comparatively small values obtained at the Southern Hemisphere stations especially during the Mike shot, are immediately evident from the fallout maps. The northern part of the Northern Hemisphere, however, received equally small depositions. The distribution of fallout for the Pacific stations appears to be consistent with the features of the meteorology described, although the branching of the cloud south of Japan in the Mike pattern is based only on scanty observational evidence.

It is apparent that radioactive debris produced by nuclear explosions does not possess all the desired attributes of a tracer for studying global circulations. Information concerning the magnitude and distribution of the radioactivity that remains airborne after the initial fallout is not available. The debris, being particulate, is washed out of the atmosphere and cannot be strictly treated as a conservative property. Thus, for example, the depositions in the Southern Hemisphere may have been low because most of the debris was rained out as it passed southward through the Intertropical Convergence Zone. In addition, the most effective sampling program for the debris provides only the crudest measure of the fallout. Yet, despite these limitations, it appears that the meteorologist can obtain useful information by operating such a network of gummed films during nuclear test periods. Although it is not proposed that special nuclear tests be undertaken for meteorological purposes, it seems reasonable to expect even greater value from future tests using an expanded network and having detonations at other locations and times.

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f barb, 5 knots.

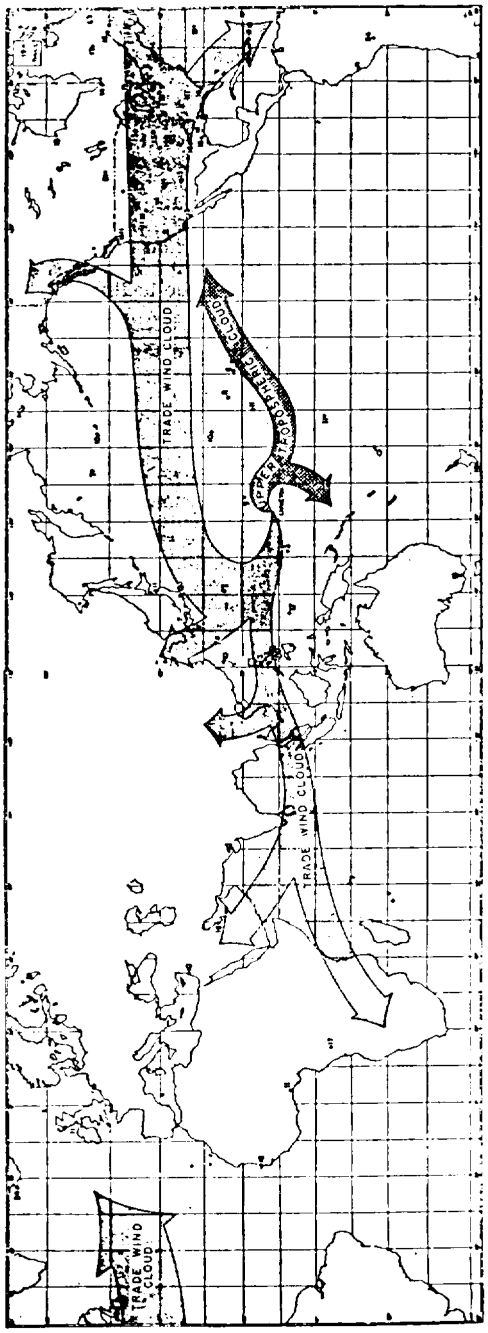
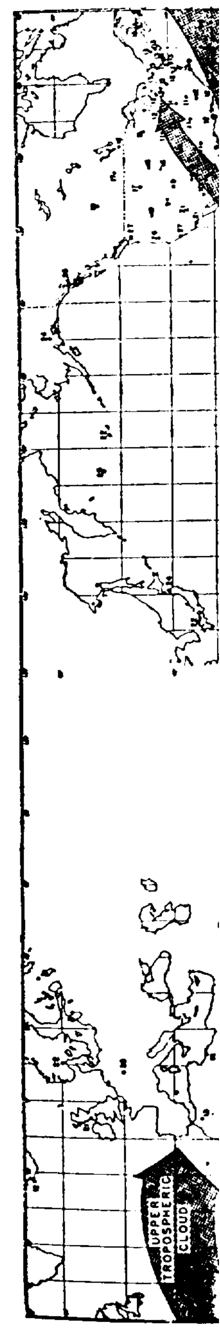


FIGURE 2.—Early history of the Mike cloud. The figures indicate the number of days between detonation and the first ground observation of fission products.

Hearings JCAE
Radioactive Fallout
1957, Pt 1



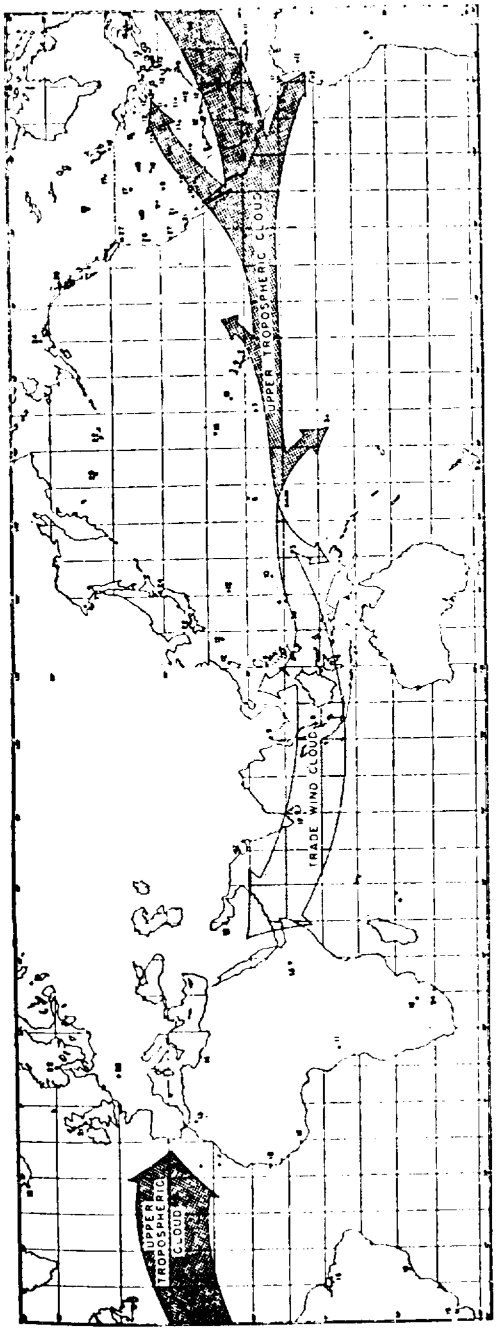


FIGURE 3.—Early history of the Bravo cloud. The figures indicate the number of days between detonation and the first ground observation of fission products.

Hearings JCAE
Radioact. Fallout
1957, Pt. 1

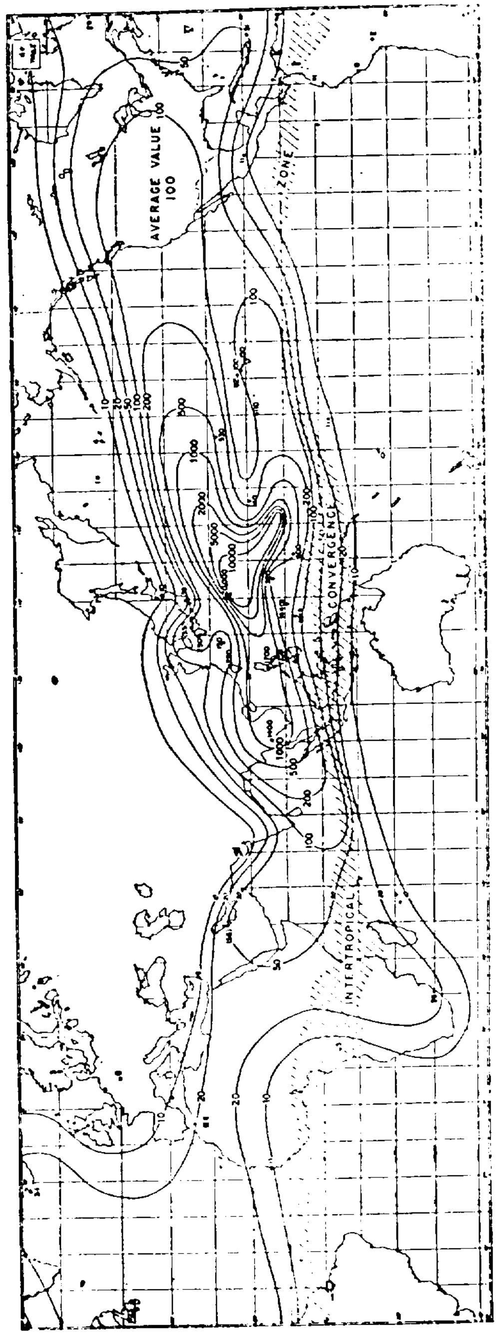


FIGURE 4.—Total radioactive fallout from the Mike cloud in the period from 2 to 35 days after detonation, in millicuries per 100 square miles. Hatching indicates the approximate November position of the Intertropical Convergence Zone, the belt of low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

Hearings JCAE
Radioact. Fallout
1957, Pt 1

low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

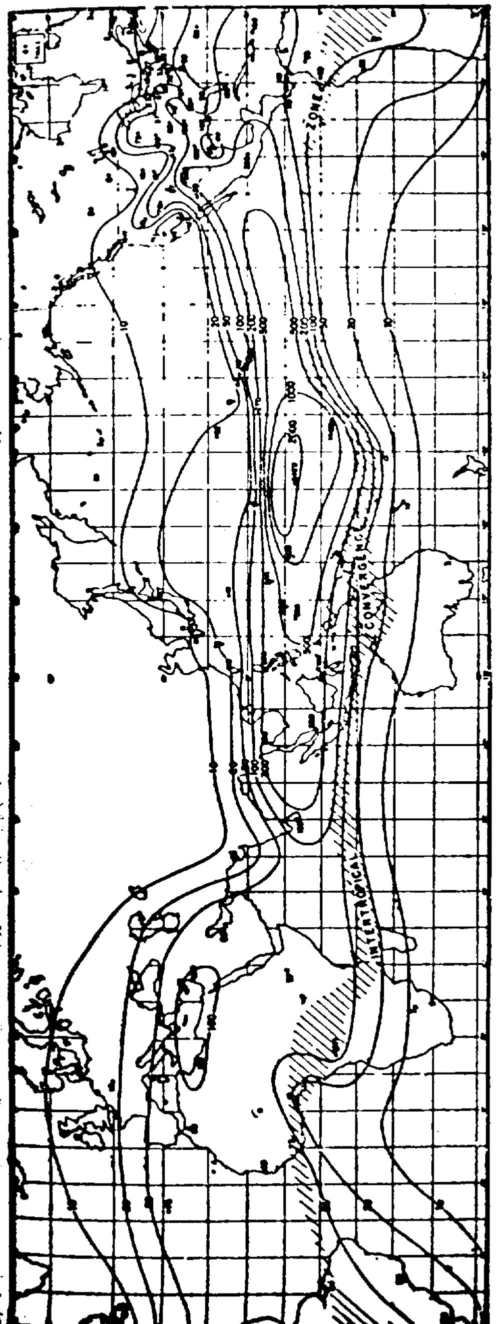


FIGURE 5.—Total radioactive fallout from the Bravo cloud in the period from 2 to 35 days after detonation, in millicuries per 100 square miles. Hatching indicates approximate March position of the Intertropical Convergence Zone, the belt of low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

Hearings JCAE
Radioact Fallout
1957, Pt. 1

Our next witness is Dr. Gordon Dunning from the Divisio Biology and Medicine of the Atomic Energy Commission.

Dr. Dunning will testify on the topic of Local Fallout: The Me anisms by Which It Can Affect Man and the Measures He Can T to Minimize Exposure.

Dr. Dunning, we note that you have a distinguished biogra and your biography will also be inserted with your remarks.

The committee will be in order. The acoustics in this room very bad, and we will ask our guests to be as quiet as possible so can hear. We will ask the witness to speak up a little bit louder th usual in his testimony so that all the people can hear.

STATEMENT OF DR. GORDON M. DUNNING, DIVISION OF BIOLO AND MEDICINE, ATOMIC ENERGY COMMISSION[3]

Dr. DUNNING. Mr. Chairman, since there is so much relevant ma rial on this subject, if it pleases the committee, I would like to sub the rather voluminous written report for the committee.

Representative HOLIFIELD. Without objection, this report and letter from David T. Shaw, Assistant General Manager of the AEC will be received for printing in the record, and you may give su summary as you feel necessary.

(The documents referred to follow:)

RADIATIONS FROM FALLOUT AND THEIR EFFECTS

Gordon M. Dunning, Division of Biology and Medicine, United States Ato Energy Commission, Washington, D. C.

FORMATION OF RADIOACTIVE PARTICLES

At the time of detonation of a nuclear weapon, about 60 different isotopes formed, representing some 35 elements. Most of these give rise to decay cha consisting of several isotopes so that there may be 170 isotopes produced en tually.

In terms of activity, a 1-megaton detonation (1 million tons) TNT equiva energy produced by fission of atoms will result in about 300,000 megacurie radioactivity, measured 1 hour after the burst. In addition there may be pres induced radioactive isotopes resulting from the reaction of neutrons released the time of detonation, with natural materials such as soil and water. (A fus reaction produces no radioactive substances directly but may cause induced tivity because of its release of neutrons.) The total radioactivity of the prod of a fission reaction will greatly exceed that of the activity induced in the soi water. In the case where the fireball clears the ground, there will be a re tively small percentage of the total fission product activity deposited aro ground zero and the neutron-induced activity probably will be much grea However, none of the neutron-induced isotopes that might be produced in preciable quantities have long half-lives.

Shortly after a nuclear burst, some of the radioisotopes combine with oxy to form negative radicals while the halogens form halides which combine w the strongly electropositive elements to form compounds. The noble gases s as radiokrypton and radioxeon remain in the atomic state until they decay

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[3] Date and place of birth: September 11, 1910; Cortland, N. Y. Education: S Teachers College, Cortland, N. Y., 1929-33; New York University (6 weeks), 1933; S Teachers College, Cortland, N. Y., 1934-36; M. S. (Sci. Edu.), Syracuse University, 1 doctor of education, 1948. Work history: Teacher, Middletown, N. Y., 1937-41; U Army (Lt. Col.), 1942-46; instructor, New York Agricultural and Technical Insti Alfred, N. Y., 1947-48; teacher, Phy. & Phy. Sci., Indiana, Penn., 1948-51; A Biophysics Rea. Anal. Div. B&M, 1951-53; AEC, Biophysicist, Division of Biology Medicine, 1953-55; AEC, Radiation Effects Specialist, Division of Biology and Medi 1955 –. (Submitted by the Atomic Energy Commission.)

aughter isotope which can form an oxide or halide. With the rapid cooling of fireball, there is condensation of the isotopes and inert materials.

In the case of an air burst there will be available only small quantities of rela- fine particles of dust in the air and debris from the bomb casing to act as transport vehicle for the radioisotopes. When the fireball intersects the ground intense heat melts or vaporizes large quantities of soil and transports them to act as carriers for the condensing radioisotopes. A characteristic toroidal tion sweeps this debris in and around the fireball where the melting tempera- is reached and the particles come in contact with the fission products still gaseous form. Subsequent cooling results in the radioactive isotopes becom- associated within and on the surface of the particles. It has been estimated from 50 to 90 percent of these particles are between 50 and 1,000 microns diameter. Of these, probably less than half of the larger particles falling out the site of the detonation will possess any activity, since most particles will reach sufficiently high temperatures to incorporate the radioactive materials, dry, relatively cool, soil is a poor scavenger.

The high yield weapon detonated at the Pacific proving ground in the fall 1952 resulted in a crater in the coral nearly a mile in diameter and 175 feet ep. Although a minor factor in the crater production might have been the mpression of the coral by the blast, probably more than a hundred million tons material were dislodged and thrown into the air. The exact results might not reproduced for a detonation over continental land areas or built-up cities but general the effects would be similar.

DISTRIBUTION OF RADIOACTIVE PARTICLES

For nominal bombs (in the range of 20-kiloton yield) the atomic cloud will not above the tropopause. (The tropopause marks the level below which is the rbulent airflow of the troposphere and above which is the relatively stable non- rbulent air of the stratosphere). The cloud from a high yield weapon will pene- ate into the stratosphere as illustrated by the photograph on page 196 of the det- nation during Operation Ivy in the fall of 1952. Two minutes after the explosion cloud had risen to 40,000 feet and 10 minutes later neared its maximum height over 100,000 feet. The smaller particles carried into the stratosphere will ttle only very slowly until they reach the troposphere where the turbulent air d rainfall will carry them much more rapidly to the earth's surface.

The stratospheric storage is uniquely significant since the mixture of radio- otopes present there is enriched in strontium 90, the element of most concern long-term hazards. This is because strontium 90 has a gaseous precursor rypton 90 with a half life of 25 seconds. Thus, at the time when conditions are timum in the fireball for the oxides and halides to become associated with olten inert particles, only a fraction of strontium 90 has formed and the gaseous rypton parent is largely carried into the stratosphere. This results in the nearby llout (within several hundred miles downwind) being partially depleted in rontium 90 while at more distant areas will be enriched.

The activity placed in the stratosphere circles and recircles the earth, first at same general latitude as the burst and then slowly spreading laterally. At the me time there will be a slow diffusion into the tropopause. Initially, there will more deposition in the same hemisphere (northern or southern) in which the rst occurred but after many months the rate of deposition may become more erally uniform over the entire earth's surface. In terms of strontium 90 about to 20 percent of the activity remaining in the stratosphere may descend each ar.

The distribution of the nearby fallout (up to several hundred miles down- nd) from high yield weapons detonated near the earth's surface will be deter- ned principally by particle size, initial position in the stem and cloud, and by wind structure at various altitudes. The particle sizes and the distribution of particles within the stem and cloud are principally functions of the yield the bomb, the nature of the surface over which the burst occurs and the quan- of material vaporized. There are uncertainties in our knowledge but figure 1 nts one generalized concept of such an initial distribution. Although the d may be 100 miles in diameter the activity probably is not uniformly dis- buted, but rather is more concentrated near the central and lower portions of cloud.

The influence of the wind structure at various altitudes on the ground distribu- of the nearby fallout is qualitatively represented in figure 2. The last sketch in figure 2 illustrates the effects of the "shearing" action of the winds whe travel in different directions and/or speeds at the various altitudes through the particles must fall. Due to these wind conditions, it is possible to obta out patterns ranging from one looking like an ink blot around ground zero extreme, to other situations where the fallout material is spread in a lon finger. In general, the pattern may be expected to approximate an ellipse.

It is clear that such variables as wind conditions and the yields of bombs and their positions of detonation above different types of surface it possible to predict fallout patterns precisely. In the case of nuclear wea testing these variables are either known or can be predicted with good accu However, in civil defense planning, certain assumptions concerning these bles must be used in estimating not only a single fallout pattern, but als sible overlapping patterns in the event of multiple detonations.

RADIATIONS AND FALLOUT

In describing and evaluating the effects of fallout patterns, it is nece to consider the characteristics of the radiations emitted from the radio material. These are of three types: Gamma rays, beta particles, and particles. Gamma rays are the emissions of principal concern, because of greater penetrating power. The most energetic beta particles travel only yards in air and are of concern only when the fallout materials remain in tact with or in very close proximity to the skin, or when the emitting mate find their way into the body. The amount of alpha-emitting isotopes asso with fallout material is considered to be of relatively minor consequence.

EXTERNAL GAMMA EXPOSURE

The gamma radiation dose that one may actually receive and the biolo effects are dependent upon a number of factors, as follows:

1. Radiological decay

The decrease in radioactivity of fallout material roughly follows the rela ship of $(time)^{-1.2}$. This means that, for every sevenfold lapse of time aft nuclear explosion, there will be a tenfold reduction in dose rate. For exam if fallout occurs 1 hour after a detonation, such as might occur for 20 o miles around ground zero of a high-yield weapon, the dose rate will be tenth of its initial value by the seventh hour. An additional tenfold reduc would require 7 times 7 hours or approximately 2 additional days of waiti The theoretical[1] dose accumulated from the first to seventh hour after deto tion would be approximately the same as that from the seventh hour unti week later. Further, this first-week dose would be about twice as great as entire remaining dose possible for the lifetime of the activity (fig. 3). T rapid decay suggests the benefits of protection in the early periods after fall and, where possible, delay of entry into a contaminated area.

In localities downwind where initial fallouts might not occur until, say, hours after a detonation, the situation would be somewhat different, in that radioactive decay would be slower. For example, consider the cases where fa out occurred at (*a*) 1 hour, and (*b*) 24 hours, after a detonation. One day aft fallout the dose rate in the first case would be one-forty-fifth of its initial a tivity (1st hour), but in the second case the dose rate would have decrea to only slightly less than one-half of its initial activity (24th hour).

The above estimates are based on an assumed radiological decay of (time) This is reasonably accurate for early periods of time after detonation, but t decay may start to vary significantly from the theoretical curve after seve months have elapsed (fig. 4). At times later than shown in figure 4 the dec curve would be expected to flatten out due to the presence of long-lived cesi 137 (27-year half life).

2. Weathering and shielding effects

The magnitude and time of occurrence of weathering and shielding make impossible to establish a single establishment of a precise rule of effects cove all situations, impossible, yet, these factors are operative in determining total exposure received from fallout.

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[1] Calculations of theoretical doses are based on (*a*) the radioactivity decreasing acc ing to $(time)^{-1.2}$, (*b*) there is no loss of activity by weathering effects, and (*c*) the per is out of doors for the time considered.

One example of weathering effects was after the March 1, 1954, fallout on the Marshall Islands in the Pacific. Figure 4 shows the gamma dose rates on the island of Rongelap over a period of about 2 years. In the first 10 days when the winds were light and there was no rainfall, the decrease in activity was roughly consistent with known radiological decay rate. The break between the 10th and 25th day undoubtedly represents the effects of rain which was known to have occurred in that period. Figure 4 suggests, however, that any further reduction in contamination by rainfall was slight.

An example of the effects of winds, occurred after one of the nuclear detonations at the Nevada test site in 1953. Strong winds blew almost at right angles across a narrow band fallout field on the 2d and 3d day after the detonation. The gamma dose rates at 3 feet above the ground on the 4th day were less than predicted by the relationship of $(\text{time})^{-1.2}$ by factors ranging from 3 to 6, while the activity of the soil samples collected on the first day and taken into the laboratory did decrease approximately as $(\text{time})^{-1.2}$. This effect of winds would not be expected to be as great for large contaminated areas of nonsandy soils.

Calculations of shielding and attenuation factors for different types of materials and theoretical calculations for various structures are plentiful (references through 11) (table 1), but more information based on actual field experience is needed. Limited data were obtained during Operation Teapot (spring 1955) where film badges were placed inside and outside of buildings for several days. The ratio of out-of-doors to indoors doses ranged from 1.3 to 7 with 1-room frame buildings providing the least attenuation factor and multiroom concrete block buildings the greater values. This program will be expanded during Operation Plumbbob as will the program of estimating personnel exposure by having a large number of people living around the Nevada test site wear film badges during and following the test series.

3. Gamma energy spectra

The relative biological effectiveness of differing energy photons and their varying depth-dose curves has been shown for X-rays (12). Similar results have been obtained for gamma rays as illustrated by one set of experiments (13) using burros where there was a shift of LD 50/30 values (lethal dose to 50 percent of the exposed animals who died in 30 days) from 684 roentgens with cobalt 60 (1.25 Mev mean energy) to 585 roentgens with Zr-95—NB-95 (~0.7 Mev mean energy). The gamma energy spectra from the mixture of isotopes in fallout is quite complex and is further complicated by the presence of scattered radiation, with its lesser energies, mixed with the direct radiation. Figure 5 illustrates the estimated gamma spectra at 3 feet above the ground following the detonation of March 1, 1954, at the Pacific Proving Ground (14).

4. Geometry of the source

The geometry of the source can make a significant difference in depth-dose curves and resultant biological effects. This may be illustrated by one experiment using swine where the LD 50/30 values for external dose decreased from 500 to 350-400 roentgens when the exposure was changed from unilateral to bilateral (the radiation exposure was first on one side only, then from opposite sides of the subject) (12). With a fallout field, the source probably would be more radial, thus a roentgen as measured in air would have more biological effect than one where the source is unilateral such as from the immediate radiations at the instant of a burst (although there is some scattered radiation), or from X-ray machines which have been used frequently with unilateral beams in developing data on biological effects of radiation.

5. Biological repair factor

It has been recognized that, in general, the longer the period over which a given radiation dose is delivered, the less is the resultant biological effect, except for such aspects as the genetic effects and life shortening. In situations of heavy fallout and relatively large potential radiation doses, the biological repair factor may be considered in estimating incapacitating and lethal doses. Since past experiments usually have been designed for other purposes, the data from these do not readily elucidate the rate of repair or the proportions of reparable and irreparable damage resulting from differently timed doses. Varying relationships have been demonstrated, depending upon the species or even the strain of animal, as well as the criteria selected for study, such as skin damage, life shortening, and LD 50 values. Our present knowledge does not permit establishment of a precise overall relationship for timed doses versus biological effects;

yet there are sufficient convincing data to permit an attempt at estimating the effect of this phenomenon.

Blair, Smith, Sacher, Davidson (15, 16, 17, 18, 19) and others have made extensive analyses of existing data on the effects of time-spaced doses for several species of animals. Generally, the recovery rate for larger and longer-lived mammals, such as dogs, is significantly less than for mice. One estimate places the half-time recovery for man as long as 4 weeks (the time for one-half of the biological damage to be repaired) (19).

Since the estimated rate of biological recovery for man is relatively slow, this factor would have its greatest influence where a given total radiation dose was delivered *over long periods of time*. This would be the case where the fallout occurred at later times after detonation rather than close-in areas where the fallout is essentially complete in about an hour after the burst, and about one-half of the total possible dose is delivered in the first 24 hours.

NEARBY FALLOUT FROM HIGH YIELD WEAPONS

As an exercise during the National Association of Civil Defense Directors meeting in Washington, D. C., on April 15–17, 1957, it was assumed the 4 bombs were dropped simultaneously as follows: 20 megaton on the Union Station, Washington, D. C., 5 megaton on the National Airport, 20 megaton on Baltimore, Md., and 10 megaton on the Patuxent River Naval Air Station. The map on page 195 shows that combined fallout from these 4 bombs. The isodose rate lines are in units of roentgens per hour at 1 hour after detonation. By this time essentially all of the fallout would have occurred in these nearby areas.

Recalling that the radioactive decay is rapid for this fallout that occurs early after detonation, it becomes evident that if adequate protective areas are available it would be wiser for people to remain in place, rather than be exposed out of doors during the period of highest activity. Likewise, if a delay in movement is possible there will be more of an opportunity to evaluate the situation and to then affect an orderly evacuation.

Since each situation will be unique, no rigid criteria will be proposed here for permissible exposures or for mandatory evacuation, since there may be other *factors present as potentially hazardous as radiation*. Rather, table 2 was developed to illustrate the kind of thinking and planning possible for civil defense. Three levels of exposure to civil defense workers are shown. The lowest of 25 roentgens is much higher than is permitted in peacetime, yet most personnel will retain their full working capacity even with exposures up to 100 roentgens.

Table 2 suggests several points relative to rescue. One of these, is that higher permitted radiation exposures to rescue crews would allow earlier entry into the contaminated area to affect first aid and general rescue work. Also, in the case of relatively little protection to the populace, there would be a saving in radiation exposure to them. On the other hand, people better sheltered, as illustrated in column V, would receive less total expoure if they stayed in the protected areas until the out-of-doors activity had decreased, and at the same time a delay of entry into the contaminated area would result in less radiation exposure to the rescue crews who might then be used again for other missions.

DISTANT FALLOUT PATTERNS FROM HIGH YIELD WEAPONS

The discussion above suggests the wide variability possible in distant fallout patterns from high-yield weapons and the great variation in radiation dose that one may receive due to shielding and weathering effects. Therefore, the following analysis is intended to be only a generalized one to illustrate the parameters and how they may operate in determining the radiation doses.

Consider the case of fallout from a high-yield weapon where people continue to live in an area without any special measures to protect themselves. Assume (*a*) for the first week following the fallout, the measured gamma activity decays according to $(time)^{-1.2}$, for the second week $(time)^{-1.3}$, and for the third week and thereafter $(time)^{-1.4}$, and (*b*) the shielding factor afforded by normal housing will reduce the out-of-doors daily dose by 25 percent, and (*c*) the half-time of repair of biological injury is 4 weeks. Probably all of these assumptions are conservative, i. e., they overestimate the hazard. Based on these assumptions, figure 6 shows the dose rates at time of fallout or entry into an area that might produce an "effective biological dose" (the term given to the radiation exposure according to the above assumptions) of one roentgen (20). This graph may be extrapolated to other readings. For example, if a fallout begins 5 hours after detonation and the dose rate at that time is 10 r. per hour, about 67 r. (effective biological dose) will be accumulated provided personnel continues to live normally in the contaminated area. This is computed as follows:

$$\frac{10}{0.15}=67$$

It is frankly recognized that in any single curve, such as that shown in figure 6, there are inherent a number of uncertainties. Criteria based on deliberate analyses of the relevant data, however, may be more valid than those determined under the duress of an emergency situation. Such a simplified graph might provide radiological monitors with a quick, even if rough, estimate of the potential hazards and thus assist in making decisions on questions such as evacuation.

Using figure 6, the idealized fallout diagram on page — was constructed to illustrate a possible pattern from a single high-yield surface burst (20).

The two innermost isodose lines shown were selected to suggest regions where (a) a significant percentage of personnel might be expected to die (400 r.) and (b) a few percent to become ill (100 r.), assuming continued occupancy of these areas with no special protective measures. These percentages would, of course, rise within the encompassed areas. The 50 r. effective biological isodose line has no unique significance, but suggests the magnitude of dose which might call for emergency measures against radiation exposures even in the face of other possible hazards. Table 3 shows the approximate areas encompassed by the three isodose lines. For areas where the fallout occurs a few hours or more following detonation, many days or weeks will be required to accumulate the major portion of effective biological doses, so that spot decisions involving additional hazards might not be necessary.

The question is frequently asked as to the time one must spend within a shelter or remain outside of a contaminated area. The answer depends upon a number of parameters, such as the criteria established for maximum permissible dose, as well as length of stay within the area of contamination . With knowledge of the magnitude of the radiation levels present and an assumed rate of decay, $(t)^{-1.2}$, it is possible to plan and execute a short stay, even in a highly contaminated area. Planning for continuous occupancy requires more extensive analysis. The following data may aid in such evaluation.

The fall out map (idealized fallout diagram on page 196) and table 3 suggest the degree of radiation exposure received in continuous occupancy under normal living conditions beginning with the time of initial fallout. For those entering the contaminated zone 4 months after the first fallout, however, and then living there indefinitely, the area encompassed by the 50 r. effective biological isodose line will have shrunk from about 25,000 to 2,500 square miles. At such time (4 months after fallout), an area of about 1,000 square miles within the 50 r. isodose line might have the highest residual contamination, amounting to about 3 times the does rates at the periphery. The 0.3 r. per week, out-of-doors, isodose-rate line might extend to about the same position as the line marked "50" on the map.

As one attempts to extrapolate such data to 1 year after fallout, the analysis becomes still more difficult and uncertain. The data suggest, however, that if return is postponed to 1 year after fallout, the 50 r. effective biological isodose line will have disappeared. On the basis of these conservative estimates, the 1,000 square miles of highest contamination might have an out-of-doors dose rate of about 4 r. per week after 1 year. Similarly, personnel might accumulate a dose of about 100 r. for the first year following their return, and an additional 90 r. over the next 3 years, independent of the biological recovery factor. It is to be expected that this factor would be relatively great for such long periods of time, thus reducing the effective biological dose below 50 r. The 0.3 r. per week, out-of-doors, isodoserate line might encompass an area somewhat larger than the line marked 400 on the map (20).

For such effects as genetic, it is the total dose received that is important, since biological repair does not enter in such calculations. According to the conservative estimates of weathering and shielding used above, possibly several hundred roentgens might be delivered in the areas of heaviest contamination, from the end of the first year after the fallout occurred until the radioactivity had decreased to essentially zero. However, the foregoing analyses are based on passive factors only, not taking into account the actions of persons themselves in reducing contamination. If, for example, a permanent return into an area were poned for 1 year after fallout, the radiological situation probably would been adequately appraised, and decontamination operations initiated. subject will be discussed by others.) Moreover, with the return of a pop into a known contaminated area, more than normal precautions might be exp in regard to occupancy of the more protective types of buildings and redu of time spent out of doors.

Of course, greater degrees of contamination could result from multiple, o lapping, fallout patterns. There is a need for continuing studies of these pr lems.

ENVIRONMENTAL CONTAMINATION

Radioactive contamination of an area will, of course, influence agricul pursuits. An evaluation of these problems involves complex and difficult st which will not be attempted here. In terms of civil defense, however, the one phase that should be noted here.

The relatively heavy fallout that occurred on some of the Marshall Island March 1954 provides the most direct data. Since the time of this fallout have been 10 radiological and biological surveys of these islands. All of data are summarized in a report prepared by the Atomic Energy Commission in press with the Government Printing Office (21).

There are strikingly wide variances in the degree of gross contamination the soils and in the plant and animal life. Likewise, relatively large range values were found for the individual isotopes in the plants and animals. conclusions, therefore, must be of only the most tentative and generalized na

The data do suggest that, in terms of strontium 90, the isotope of princ concern, this activity built up in the plantlife over the first year after fallout then started decreasing slowly. By using very rough approximation, and ex polations, the data suggest that, if plantlife had been growing in the are great contamination, i. e., where the gamma dose rates extrapolated to H 1 hour would have been 2,500 roentgens per hour, it might have contained 10 microcuries of strontium 90 per kilogram of calcium, at 1 year. The correspo ing values for the soils are several times higher. If an assumption is made th there is a discriminatory factor of about 4 for the Sr-Ca ratio in plants vers bones, the above data suggest possible levels of strontium 90 in the bones animals from continuous consumption of this food of a few to several microcuri of strontium 90 per kilogram of calcium. The maximum permissible body burde for adult atomic-energy workers is 1 microcurie of strontium 90 per kilogra of calcium.

There is some confirmatory evidence for this crude evaluation. A variety native animals were left on the island of Rongelap after the fallout in Marc 1954. They have been collected and sacrificed serially in time. Even after years of continuous occupancy, it was reported that there were no pathologic changes that could be ascribed to radiation (22). Their bones showed fro about a one-tenth to a few tenths of a microcurie of strontium 90 per kilogram o calcium. Since the areas of highest contamination were about 12-14 times greate than Rongelap, an extrapolation would suggest values in the same range as abov i. e., a few to several microcuries of strontium 90 per kilogram of calcium i animals had lived in the area of great contamination.

The Pacific island soils have higher calcium content than most soils in th United States, and of course there are differences in the type of plantlife an in the climate. However, theoretical calculations suggest that the same fallout i the United States might result in something like 100 microcuries of strontiu 90 per kilogram of calcium in the soils with the highest contamination. Wit assumed discriminatory factors from soil to bones of 10 or more, the implie eventual body burden of strontium 90 is of the same magnitude in the Pacifi

The uncertainty of these data, however, would not deny the possibility that a similar fallout in the United States there might eventually result a body burde of 10 or more microcuries per kilogram, if people were to subsist entirely food from the area of highest contamination. With maintained values 2 to times this amount, it might be expected that a few percent might die of bo tumors after a latent period of 15 to 20 years. It would be expected, howeve that the strontium 90 content in the food supply would slowly decrease with tim Any measures taken to reduce the uptake of strontium 90 into the food suppl and any supplemental foods from less contaminated areas would lower th strontium intake.

For civil-defense purposes, a full evaluation of the whole environmental contamination problem is needed, especially for the cases of multiple, overlapping, fallout patterns from many nuclear detonations which might occur under wartime conditions.

EXTERNAL BETA EXPOSURE

The second principal emission from the fallout material is beta particles. These are essentially high-speed electrons, of which even the most energetic travel only a short distance into the skin. (See the next section for discussion on internal exposures.) If large enough radiation doses are delivered by these beta particles, the skin may first show erythema (reddening) and then proceed to more serious damage. If a sizable fraction of the body should suffer serious skin damage from these beta radiations, the results would be similar to those from thermal burns, i. e., serious injury or death.

There is little doubt that "beta burns" can and have occurred. In the case of the Marshallese who were in the fallout from the detonation at the Pacific on March 1, 1954, most of the more heavily exposed showed some degree of skin damage, as well as about half of them showing some degree of epilation due to beta doses (22). However, none of these effects were present except in those areas when the radiation material was in contact with the skin, i. e., the scalp, neck, bend of the elbow, between and topside of the toes No skin damage was observed where there was a covering of even a single layer of cotton clothing. In fact, the beta radiations emanating from the radioactive material on the ground should have been adequate to produce detectable skin damage (based on the amount of contamination present), yet this was not observed.

These findings indicate the obvious benefits to be expected from (*a*) remaining inside during the time of actual fallout to reduce the possibility of direct body contamination, or, if out of doors, to keep the body covered, and (*b*) early removal of the body contamination, since higher doses are delivered during early times after fallout.

The Marshallese, were semiclothed, had moist skin, and most of them were out-of-doors during the time of fallout. Some bathed during the two-day exposure period before evacuation, but others did not, therefore, there were optimal conditions in general for possible beta damage. The group suffering greatest exposure showed 20 percent (13 individuals) with deep lesions; 70 percent (45 individuals) superficial lesions; and 10 percent (6 individuals) no lesions. Likewise, 55 percent (35 individuals) showed some degree of epilation followed by a regrowth of the hair. However, during this same period of time they received a whole-body gamma dose of 175-roentgens—a value approaching lethality for some of those exposed. These data, together with others, indicate that the external gamma radiation would be the controlling factor for making such decisions as to evacuation, although recognizing that any beta exposure would be an additional body insult.

INTERNAL EXPOSURES

The principal factor in evaluating long-term hazards from ingestion and inhalation is the doses delivered to the bones by isotopes of strontium. This subject will be discussed in detail by others.

The principal hazards from intake of relatively large amounts of radioactive fallout for several weeks immediately following a nuclear detonation are doses to the:

(*a*) gastrointestional tract, from the gross fission product activity,
(*b*) thyroid, from isotopes of iodine, and
(*c*) bone, principally from isotopes of strontium and barium-lanthanum.

The solubility of the fallout material is a major factor in determining the resultant fate, and thus radiation doses, within the body. The solubility varies, depending among other factors upon the surface over which the detonation occurred. The fallout material collected in soil samples at the Nevada test site has been quite insoluble, i. e., only a few percent in distilled water and roughly 20 to 30 percent in 0.1 N HCl. However, it would be expected that the activity actually present in drinking water supplies would be principally in soluble form. The water collected from a well and a cistern on the island of Rongelap about 21 months after the March 1, 1954, fallout, was found to have about 80 percent of the activity in the filtrate, but there was an undetermined amount that settled to the bottom. Other data suggest the material to have been about 10 to 20 percent soluble in water.

Figure 7 shows relative doses to the body organs, based on the assumptions that (*a*) 90 percent of the material is insoluble (when calculating doses to the gastrointestinal tract), (*b*) all of the isotopes of iodine are soluble (w estimating doses to the thyroid), and (*c*) 25 percent of the ingested stronti isotopes and 7 percent of the barium-lanthanum reached the bones. It may seen that ingestion of a given amount of fission product activity on the fourth fifth days may result in nearly 2½ times the dose to the thyroid as to the low large intestine. For a continuous consumption of fallout material from the hour to the 30th day the ratio of doses is about 1.7. Table 4 indicates the am of ingested fission product activity to produce 1 rad dose to the lower la intestine.

Analyses of past data strongly indicate the quantity of fallout material ta in for times immediately following a detonation: (*a*) by inhalation is very m less than by ingestion (unless of course one does not eat or drink), and (*b*) m come from surface contamination of the food rather than by the soil-plant-anim cycle.

How much intake is actually permitted depends upon many factors includ the essentialness of the food and water to sustain life, and one's philosophy acceptable biological risks and damages in the face of other possible hazar such as mass evacuation. By using table 4 and figure 7, an estimate may made of the radiation doses that might result from the ingestion of a giv amount of fission product activity. In determining how much actual ingest and thus the radiation doses that might be permitted, reference may be mad to table 5 which suggests the biological effects from certain doses.

Such evaluations as attempted here are necessary and valuable for plannin purposes, but once the fallout occurs the emergency of the situation may preclu immediate analysis of the food and water supplies. Further, the abstinence fro food and water because it might be contaminated could not be continued inde nitely. Therefore, the following three commonsense rules are suggested:

1. Reduce the use of contaminated food and water to bare minimum unti adequate monitoring can be performed: use first any stored clear water and canned or covered foods; wash and scrub any exposed foods.

2. If the effects of lack of food and water become acute, then use what ever is available but in as limited quantities as possible. Whenever possible select what seems to be the least likely contaminated water and/or foodstuffs.

3. Since it is especially dsirable to restrict the intake of radioactivity in children, give them first preference for food and water having the lowest degree of contamination.

In an area of heavy fallout one matter to consider is the relative hazards from the external gamma exposure versus internal doses from ingestion of the material. One of the best evidences on this point was the fallout that occurred on the Rongelapese in March 1954. Those in the highest exposure group received 175 roentgens whole body external gamma exposure yet their body burdens of internal emitters were relatively low (22). These and other data suggest that:

If the degree of contamination of an area for several weeks immediately following a nuclear detonation is such that the external gamma exposure would permit normal and continuous occupancy, the internal hazard would not deny it.

This is based on such reasonable assumptions of (*a*) about 50 percent reduction of gamma exposure from out-of-doors doses afforded by living a part of each day in normal family dwellings, (*b*) washing and/or scrubbing contaminated foods, and (*c*) excluding areas where relatively little fallout occurred, but into which may be transported highly contaminated food and/or water. After longer periods of time during which the gamma dose rates in an originally highly contaminated area have decreased to acceptable levels, it probably would be necessary to evaluate the residual contamination for the bone seeking radioisotopes, especially strontium 90.

NUCLEAR WEAPONS TESTING

Since 1951, the United States has conducted 11 series of nuclear tests, 5 at the Nevada test site and 6 at the Eniwetok Proving Ground, for a total of more than 63 test detonations. A sixth series is currently underway at the Nevada test site. The fallout on the inhabitants of some of the Marshall Islands in March 1954 (which will be discussed by others) and fallout on some Japanese fishermen, have been the major effects off the testing areas. The only other off-site damage has been in the United States where the blast wave has caused minor structural damage for which about $45,000 has been paid in claims (23), and fallout that occurred on some horses and cattle grazing within 20 miles of ground zero causing skin burns for which about $15,000 was paid.

At the Eniwetok Proving Ground, where the larger devices are tested, the warning area covers nearly 400,000 square miles. This area is under constant surveillance during the time of testing both by surface ships and by aircraft. Starting 2 days prior to a detonation, the search is intensified in the sector of probable fallout. If any transient ship is located in the warning area, it is advised to leave and the detonation is delayed until it is clear.

Fully manned weather and fallout prediction units are an integral part of the task force conducting the tests. Since the larger detonations in the Pacific require additional information on the upper air, new types of high-altitude balloons and missiles are used. Nine weather stations are established by the task force during the test series on islands around the site, in addition to the eight regular weather stations in operation on other islands.

After each detonation, aircraft track the radioactive air out for several hundred miles. Other aircraft, with special monitoring equipment fly over land and sea areas to measure any residual contamination.

Through the cooperation of the United States Public Health Service, trained monitors were present during Operation Redwing (spring 1956 series) on the populated islands of Wotho, Ujelang, and Utirik.

As would be expected, the delineation of fallout patterns in the wide expanses of the Pacific is difficult. For the immediate monitoring, aerial surveys are conducted as mentioned above, automatic equipment are placed on land areas, and a variety of ships, skiffs, and buoys are utilized. Following each test series, large-scale radiological and biological surveys are made. Data from these surveys have been summarized by the Commission in a document soon to be published by the Government Printing Office (21).

The Nevada test site covers an area of about 600 square miles, with the adjacent 4,000 square miles being a United States Air Force gunnery range (24). Surrounding these areas are wide expanses of sparsely populated land. For general safety, as well as security, the Nevada test site is closed to the public. Aerial and surface surveys are made to insure that no persons or animals wander into the area. Each nuclear detonation is publicly announced ahead of time.

As a part of the test organization there is an advisory panel of experts in the fields of biology and medicine, blast, fallout prediction, and meteorology. A series of meetings is held before the firing of each shot to weigh carefully all factors related to the safety of the public.

A complete weather unit is in operation at the Nevada test site, drawing upon all of the extensive data available from the United States Weather Bureau and the Air Weather Service, plus six additional weather stations ringing the test site. These data are evaluated for the current and predicted trends up to 1 hour before shot time. A shot can be canceled at any time up to a few seconds before the scheduled detonation. In the past, more than 80 postponements have been made due to unfavorable weather conditions.

Several measures have been used to reduce the radioactive fallout off the test site. First, of course, only small nuclear devices are tested at Nevada. Since the greater the height of the fireball above the surface the less is the fallout in nearby areas, the test towers have been extended to 500 feet, and during Operation Plumbbob (spring 1957) there will be at least one 700-foot tower. Also, a new technique of using captive balloons is being developed. Extensive tests are being conducted to determine the feasibility of detonating nuclear devices so far underground that all of the radioactive material will remain captured and thus, of course, completely eliminate any fallout.

Prior to each nuclear detonation a warning circle is established for aircraft, designed to provide control of aerial flights within the area of predicted path of the atomic cloud. A representative of the Civil Aeronautics Administration is assigned to the test organization and assists in establishing the controlled area. This may typically extend about 150 miles in radius and be in force for a period from about H minus one-half hour to H plus 10 hours. All aircraft are required to check through the Civil Aeronautics Administration before flying in this area.

After each nuclear burst, aircraft from the test organization track the cloud until it is no longer readily detectable. Behind this come other aircraft to plot the fallout pattern on the ground. This survey is repeated on D plus 1 day.

The off-site monitoring program during Operation Plumbbob (spring 1957) illustrates the extensive system organized not only to take numerous radiological measurements but also to provide close liaison with the citizens of nearby communities. The Atomic Energy Commission and the United States Public Health Service jointly organized a program wherein the areas around the test site are mapped out into 17 zones. A technically qualified man has been assigned to live in each zone. His duties consist not only of normal monitoring activities but also, prior to and during the test series, of learning the communities and families in his zone, getting to know the people and having them know him. In addition to the 17 zone commanders, as they are called, there are 8 mobile monitoring teams on call to go to any locality to assist if needed or to follow to areas outside the 17 zones.

Four additional monitoring programs are also in operation. One of these projects is primarily of research nature yet provides radiation monitoring out to 160 miles or more from the test site. A second program is a unique system of telemetering, whereby instruments are placed in about 30 communities around the test site and connected to commercial telephone wires. An operator sits at the control point and, by placing a normal telephone call, receives back signals that are translated in a matter of seconds into gamma radiation dose rates. A third project consists of automatic instruments located in another 8 communities that permanently record the gamma dose rates continuously from the beginning to the end of the test series. A fourth program consists of aerial surveys with special gamma detection instruments.

Extending outward from the test site across the country are 38 United States Public Health Service monitoring stations established in cooperation with the Atomic Energy Commission, and 11 AEC installations (see tables 6 and 7). In addition, through the cooperation of the United States Weather Bureau, stations in the United States make gummed paper collections of fallout (table 7). These gummed-paper collections are also made worldwide at 73 other locations by arrangement with the Department of State, United States Weather Bureau, United States Air Force, and Navy (table 9).

RADIATION EXPOSURES TO THE PUBLIC

The data and their evaluation concerning strontium 90 produced by nuclear weapons testing will be discussed by others at this hearing.

The external gamma exposures through September 1955 may be described briefly as follows:

"* * * With respect to the gamma dose, the average value for the United States is higher than it is for the rest of the world. The range of values in the United States is relatively narrow, 6 to 49 millirads, except for Salt Lake City (160), Grand Junction (120), and Albuquerque, N. Mex. (110). The representative dose for eastern United States is about 15 to 20 millirads, with slightly higher values in the Middle West and lower values on the west coast.

"The cumulative gamma dose at the foreign stations is in the range of 4 to 21 millirads, except for some of the Pacific islands, where the range is from 13 to 19 millirads * * *" (25).

These are infinity does, i. e., the maximum possible exposures one might receive if he were out of doors for the lifetime of the radioactivity, there were no weathering effects, and the activity decayed according to $(time)^{-1.2}$. The actual radiation exposures will vary with changes in these conditions, but roughly may approximate one-half of the infinity dose.

In summarizing, the data on radiation exposures from fallout, the National Academy of Sciences-National Research Council report said (26):

"* * * it may be stated that United States residents have, on the average, been receiving from fallout over the past 5 years a dose which, if weapons testing were continued at the same rate, is estimated to produce a total 30-year dose of about *one-tenth of a roentgen;* and since the accuracy involved is probably not better than a factor of 5, one could better say that the 30-year dose from weapons testing if maintained at the past level would probably be larger than 0.02 roentgens and smaller than 0.50 roentgens. * * *

"The rate of fallout over the past years has not been uniform. If weapons testing were, in the future, continued at the largest rate which has so far occurred (in 1953 and 1955) then the 30 year fallout dose would be about twice that stated above. * * *"

Gamma radiation exposures near the Nevada test site are generally higher that the average for the United States. The map on page 195 shows the estimated gamma exposures accumulated from all tests at the Nevada test site. Table 10 lists all of the communities that have received sufficient fallout to result in an estimated 0.2 roentgens or more to the inhabitants. In addition to this list, the highest fallout level noted to date in an inhabited place around the Nevada test site occurred in 1953 at a motor court near Bunkerville, Nev., where about 15 people might have accumulated 7 to 8 roentgens if they had continued to live there indefinitely.

The National Academy of Sciences-National Research Council Report recommended: (26)

"* * * That for the present it be accepted as a uniform national standard that X-ray installations (medical and nonmedical), power installations, disposal of radioactive wastes, experimental installations, testing of weapons, and all other humanly controllable sources of radiations be so restricted that members of our general population shall not receive from such sources an average of more than 10 roentgens, in addition to background, of ionizing radiation as a total accumulated dose to the reproductive cells from conception to age 30. * * *

"* * * That individual persons not receive more than a total accumulated dose to the reproductive cells of 50 roentgens up to age 30 years * * * and not more than 50 roentgens additional up to age 40 * * *."

The National Committee on Radiation Protection and Measurement (27) has recommended that, "The maximum permissible dose to the gonads for the population of the United States as a whole from all sources of radiation, including medical and other manmade sources, and background, shall not exceed 14 million rems per million of population over the period from conception up to age 30, and one-third that amount in each decade thereafter. Averaging should be done for the population group in which cross-breeding may be expected." (27)

Since natural background radiation is roughly 4 roentgens per 30 years, the value for manmade sources becomes about 10 million man-rems for a population of one million. This particular unit was selected because of genetic considerations, that is, radiation doses to relatively large populations. The average exposure to only those communities around the Nevada test site that experienced the greatest amount of fallout (0.2 roentgens or more) is 0.6 roentgens for the 6 years since the regular nuclear tests were started. The round numbers are 58,000 man-roentgens for 100,000 people. If the area considered around the Nevada test site is enlarged to include 1,000,000 people the average exposure is about 0.1 roentgens for the 6 years, or at a rate of about one-half roentgen per 30 years. This is one-twentieth of the recommendation of the National Committee on Radiation Protection and Measurement for maximum exposures.

The highest measured concentration of fission product activity in the air off the Nevada test site was at St. George, Utah, during the spring 1953 test series, amounting to about 1.3 microcuries per cubic meter of air averaged over a 24-hour period. It was estimated that the radiation dose to the lungs from this activity was less than that delivered every month by naturally occurring radioactive isotopes in the air that we breathe.

The highest measured concentration of activity from fallout material in water off the controlled area was at upper Pahranagat Lake, Nev., in the spring of 1955 amounting to 1.4×10^{-4} microcuries per milliliter at 3 days after the detonation. This is one-thirty-sixth of the operational guide—an amount that is considered safe for continuous consumption.

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Table 1.—Rough estimate of reduction in gamma radiation within structures

Type structure	*Percentage of out-of-doors level*
One-story frame house:	
First floor	~50
Basement (center)	~10
Basement (side)	<10
Multistory reinforced concrete:	
Lower floors (away from windows)	<10
Basement	~0.1
Shelter (equivalent to 3 feet of earth)	~0.1

TABLE 2.—*Radiation exposure*

Permissible dose to rescue crew (roentgens)[1]	Time of initial contact with populace (hours after detonation)	Dose to populace while waiting rescue (roentgens)[2]	Total radiation dose to populace (roentgens)[3]	Dose to populace while waiting rescue (roentgens)[4]	Total radiation dose to populace (roentgens)[3]
1	2	3	4	5	6
[illegible] line:					
[illegible]	5½	72	85	14	26
[illegible]	2½	40	65	8	33
[illegible]	1¼	10	60	2	[illegible]
[illegible] line:					
[illegible]	16	320	332	64	76
[illegible]	8½	260	285	52	77
[illegible]	5	205	260	41	91
[illegible] line:					
[illegible]	25	600	612	120	112
[illegible]	14	500	525	100	125
[illegible]	7¼	400	450	80	130

[1] Based on a 2½-hour mission to rescue crew.
[2] Assuming ½ of out-of-doors exposure.
[3] Assuming populace receives ½ of exposure to rescue crew.
[4] Assuming 1/10 of out-of-doors exposure.

TABLE 3.—*Approximate areas encompassed by the effective biological isodose lines shown in the map (top of p. 196)*

Isodose line (r):	*Approximate areas encompassed (square miles)*
50	25,000
100	12,500
400	5,000

TABLE 4.—*Approximate fission product activities (microcuries per milliliter of gram × 10²) to produce 1 Rad dose to lower large intestine* [1]

Duration of ingestion (days)	Start of intake (days after detonation)							
	1 (1st hour)	2 (24th hour)	3	4	5	10	15	20
[illegible]	35	2.5	1.9	1.7	1.4	1.1	1.1	1.0
[illegible]	24	1.7	1.1	0.89	0.81	0.62	0.57	[illegible]
[illegible]	15	1.3	0.82	0.65	0.56	0.41	0.40	0.37
[illegible]	13	1.0	0.65	0.53	0.46	0.33	0.30	0.29
[illegible]	12	0.9	0.57	0.44	0.39	0.28	0.25	0.22
[illegible]	9.2	0.64	0.40	0.29	0.25	0.17	0.14	0.13
[illegible]	7.8	0.53	0.33	0.26	0.21	0.13	0.11	[illegible]
[illegible]	7.5	0.49	0.29	0.21	0.18	0.11	0.089	[illegible]

[1] (a) Activities computed at start of intake period. (b) Based on intake of 2,200 milliliters or grams of [illegible] food per day for adults.

TABLE FIVE

SOME POSSIBLE BIOLOGICAL EFFECTS FROM RADIATION DOSES

TO SPECIFIC ORGANS *

Dose (Rads)	Gastrointestinal Tract	Thyroid	Bones
10,000		Minor changes in structure	
	Permanent or serious damage -- survival threatened		Tumor production
1,000	Tumor Production		
			Minor changes in structure
	Immediate effects such as nausea and vomiting		
		Potential carcinogenic dose to thyroids of few percent of children and adolescents	
100			

*Lesser short term effects would be expected from the same doses distributed in time.

TABLE 6.—*U. S. Public Health Service monitoring stations during operation Plumbbob (spring 1957)*

Albany, N. Y.	Hartford, Conn.	New Orleans, La.
Anchorage, Alaska	Honolulu, T. H.	Oklahoma City, Okla.
Atlanta, Ga.	Indianapolis, Ind.	Phoenix, Ariz.
Austin, Tex.	Iowa City, Iowa	Pierre, S. Dak.
Baltimore, Md.	Jacksonville, Fla.	Portland, Oreg.
Berkeley, Calif.	Jefferson City, Mo.	Richmond, Va.
Boise, Idaho	Juneau, Alaska	Salt Lake City, Utah
Cheyenne, Wyo.	Klamath Falls, Oreg	Santa Fe, N. Mex.
Cincinnati, Ohio	Lansing, Mich.	Seattle, Wash.
Denver, Colo.	Lawrence, Mass.	Springfield, Ill.
El Paso, Tex.	Little Rock, Ark.	Trenton, N. J.
Gastonia, N. C.	Los Angeles, Calif.	Washington, D. C.
Harrisburg, Pa.	Minneapolis, Minn.	

TABLE 7.—*AEC monitoring stations during operation Plumbbob (spring 1957)*

Berkeley, Calif: Radiation laboratory, University of California
Cincinnati, Ohio: General Electric Co., aircraft nuclear propulsion department
Idaho Falls, Idaho: Idaho Operations Office
Lemont, Ill.: Argonne National Laboratory
Los Alamos, N. Mex.: Los Alamos Scientific Laboratory
New York, N. Y.: New York Operations Office
Richland, Wash.: Hanford Operations Office
Oak Ridge, Tenn.: Oak Ridge National Laboratory
Rochester, N. Y.: The atomic energy project, University of Rochester
Salt Lake City, Utah: Radiobiology laboratory, University of Utah
West Los Angeles, Calif.: Atomic energy project, University of California, Los Angeles

TABLE 8.—*U. S. Weather Bureau fallout sampling stations in operation during Operation Plumbbob (spring 1957)*

Abilene, Tex.
Albany, N. Y.
Albuquerque, N. Mex.
Alpena, Mich.
Amarillo, Tex.
Atlanta, Ga.
Bakersfield, Calif.
Baltimore, Md.
Billings, Mont.
Binghampton, N. Y.
Bishop, Calif.
Boise, Idaho
Boston, Mass.
Buffalo, N. Y.
Caribou, Me.
Casper, Wyo.
Charleston, S. C.
Cheyenne, Wyo.
Chicago, Ill.
Cleveland, Ohio
Colorado Springs, Colo.
Concord, N. H.
Corpus Christi, Tex.
Concordia, Kan.
Dallas, Tex.
Del Rio, Tex.
Denver, Colo.
Des Moines, Iowa
Detroit, Mich.
Elko, Nev.
Ely, Nev.
Eureka, Calif.
Fargo, N. Dak.
Flagstaff, Ariz.
Fort Smith, Ark.
Fresno, Calif.
Goodland, Kans.
Grand Junction, Colo.
Grand Rapids, Mich.
Green Bay, Wis.
Hatteras, N. C.
Helena, Mont.
Huron, S. Dak.
Jackson, Miss.
Jacksonville, Fla.
Kalispell, Mont.
Knoxville, Tenn.
Las Vegas, Nev.
Los Angeles, Calif.
Louisville, Ky.
Lynchburg, Va.
Marquette, Mich.
Medford, Oreg.
Memphis, Tenn.
Miami, Fla.
Milford, Utah
Milwaukee, Wis.
Minneapolis, Minn.
Mobile, Ala.
Montgomery, Ala.
New Haven, Conn.
New Orleans, La.
New York (LaGuardia), N. Y.
Philadelphia, Pa.
Phoenix, Ariz.
Pittsburgh, Pa.
Pocatello, Idaho
Port Arthur, Tex.
Portland, Oreg.
Prescott, Ariz.
Providence, R. I.
Pueblo, Colo.
Rapid City, S. Dak.
Reno, Nev.
Rochester, N. Y.
Roswell, N. Mex.
Sacramento, Calif.
Salt Lake City, Utah
San Diego, Calif.
San Francisco, Calif.
Scottsbluff, Nebr.
Seattle, Wash.
Spokane, Wash.
St. Louis, Mo.
Syracuse, N. Y.
Tonopah, Nev.
Tucson, Ariz.
Washington, D. C. (Silver Hill, Md.)
Wichita, Kans.
Williston, N. Dak.
Winnemucca, Nev.
Yuma, Ariz.

TABLE 9.—*Foreign monitoring stations during Operation Plumbbob (spring 1957)*

Addis Ababa, Ethiopia
Anchorage, Alaska
Bangkok, Siam
Beirut, Lebanon
Belem, Brazil
Bermuda
Buenos Aires, Argentina
Canal Zone
Canton Island
Churchill, Manitoba, Canada
Clarke AFB, Philippines
Colombo, Ceylon
Dakar, French West Africa
Deep River, Ottawa, Ontario, Canada
Dhahran, Saudi Arabia
Durban Natal, South Africa
Edmonton, Alberta, Canada
Fairbanks, Alaska
French Frigate Shoals
Goose Bay, Labrador
Guam
Hilo, Hawaii
Hiroshima, Japan
Honolulu, Hawaii
Iwo Jima
Johnson Island
Juneau, Alaska
Keflavik, Iceland
Koror
Kwajalein
La Paz, Bolivia
Lagens, Azores
Lagos, Nigeria
Leopoldville, Belgian Congo
Lihue
Lima, Peru
Melbourne, Australia
Mexico City, Mexico
Midway Island
Milan, Italy
Misawa, Japan
Moncton, New Brunswick, Canada
Monrovia, Liberia
Montreal, Quebec, Canada
Moosonee, Ontario, Canada
Nagasaki, Japan
Nairobi, Kenya, East Africa
Nome, Alaska
North Bay, Ontario, Canada
Noumea, New Caledonia
Oslo, Norway
Ponape
Prestwick, Scotland
Pretoria, South Africa
Quito, Ecuador
Regina, Saskatchewan, Canada
Rhein Main, Germany
San Jose, Costa Rica
San Juan, Puerto Rico
São Paulo, Brazil
Seven Islands, Quebec, Canada
Sidi Slimane, French Morocco
Singapore
Stephenville, Newfoundland
Sydney, Australia
T'ai-pei, Formosa
Thule, Greenland
Tokyo Air Base, Japan
Truk
Wake Island
Wellington, New Zealand
Wheelus AFB, Tripoli
Winnipeg, Manitoba, Canada
Yap

[illegible] 19.—Estimated radiation exposures for communities around the Nevada test site

NEVADA

	Roentgen
[illegible]a	3.0
[illegible]n	1.3
[illegible] Springs	0.6
[illegible]	0.8
[illegible]ay	2.0
[illegible]horn Ranch	0.9
[illegible]erville	4.3
[illegible]te	0.7
[illegible]	3.6
[illegible]s Station	0.8
[illegible]line	0.7
[illegible]stal	4.0
[illegible]stal Springs	1.0
[illegible]rand	0.5
[illegible] Lake	1.0
[illegible]water	0.8
[illegible] Ely	0.6
[illegible] Creek Ranch	0.7
[illegible]h	3.5
[illegible]	0.6
[illegible]ka	0.2
[illegible]ni Ranch	0.8
[illegible]dale	0.7
[illegible]om	2.0
[illegible]ko	1.0
K[illegible]berley	0.5
Las Vegas	0.2
Lincoln Mine	4.0
Lockes Ranch	1.3
Logandale	0.4
Lund	0.8
Mesquite	1.8
McGill	0.4
Moapa	0.8
Nellis AF Base	0.05
North Las Vegas	0.2
Nyala	1.7
Overton	0.35
Pahrump	0.2
Panaca	0.65
Pioche	0.7
Preston	0.7
Reed	4.0
Rox	3.0
Ruth	0.5
Sharp's (Adaven)	1.2
Shoshone	0.7
Sunnyside	1.2
Ursine	0.6
Warm Springs	0.5
Warm Spring Ranch	1.0

UTAH

	Roentgen
[illegible]n	0.8
[illegible]derson Junction	1.2
[illegible]r Valley Junction	0.4
Beaver	0.25
Beryl	0.5
Beryl Junction	1.0
Cedar City	0.4
Enterprise	0.7
Garrison	0.7
Glendale	1.2
Gunlock	2.6
Hamilton Fort	0.6
Hurricane	4.2
Kanab	1.6
Kanarraville	1.2
Leeds	3.0
Long Valley	0.8
[illegible]	0.5
[illegible]ersville	0.2
Modena	0.5
Mount Carmel	0.85
New Castle	0.6
New Harmony	1.2
Orderville	1.5
Panguitch	0.2
Paragonah	0.4
Parowan	0.4
Pintura	1.2
Rockville	3.0
Saint George	3.0
Santa Clara	3.5
Shivwits	2.8
Springdale	2.6
Toquerville	2.0
Veyo	2.0
Virgin	1.5
Washington	3.0
Zane	0.3

ARIZONA

	Roentgen
Beaver Dam	2.0
Littlefield	1.6
Short Creek	1.6
Wolf Hole	1.3

FIGURE 1

GENERALIZED CONCEPTS: DIMENSIONS OF CLOUD AND STEM DISTRIBUTION OF ACTIVITY

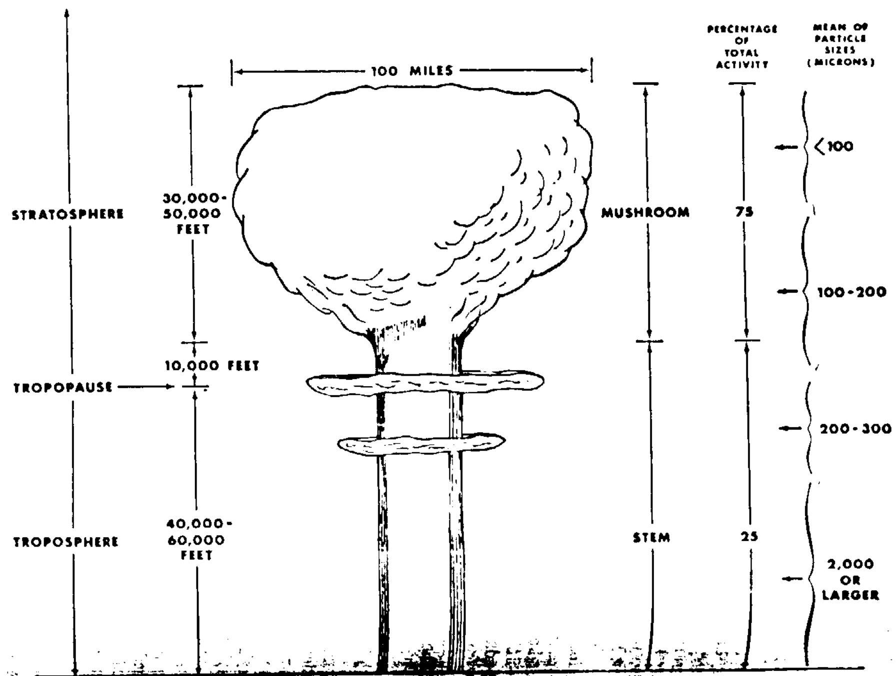


FIGURE 2a

FACTORS AFFECTING DISTRIBUTION OF FALLOUT *

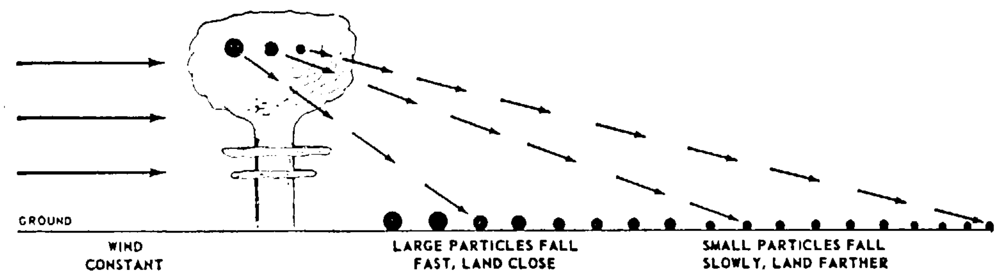
EFFECT OF PARTICLE SIZE
(WIND AND INITIAL HEIGHT ASSUMED CONSTANT)

FIGURE 26

FACTORS AFFECTING DISTRIBUTION OF FALLOUT *

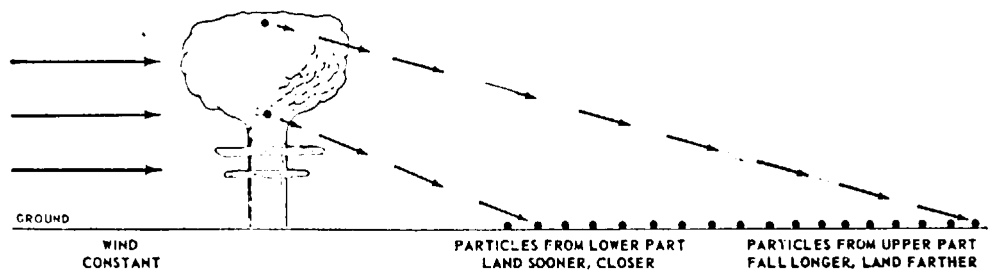
EFFECT OF PARTICLE SIZE

(WIND AND INITIAL HEIGHT ASSUMED CONSTANT)



EFFECT OF HEIGHT

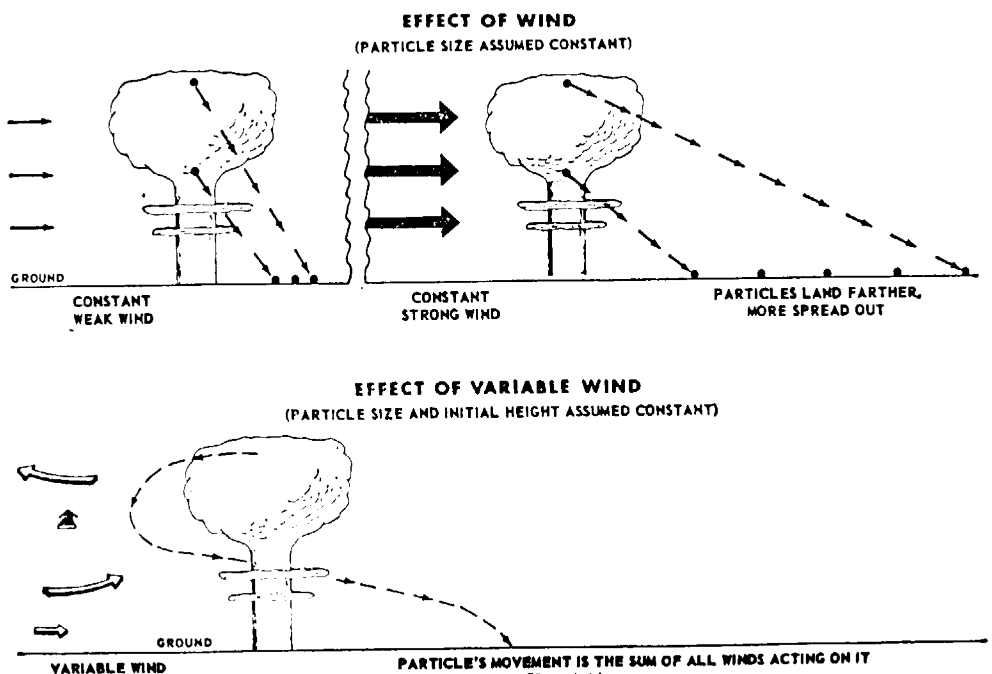
(WIND AND PARTICLE SIZE ASSUMED CONSTANT)



* As suggested in Civil Defense Technical Bulletin TB-11-21, Fallout and The Winds, October, 1955.

FIGURE 2b

FACTORS AFFECTING DISTRIBUTION OF FALLOUT *



* As suggested in Civil Defense Technical Bulletin

Figure 3

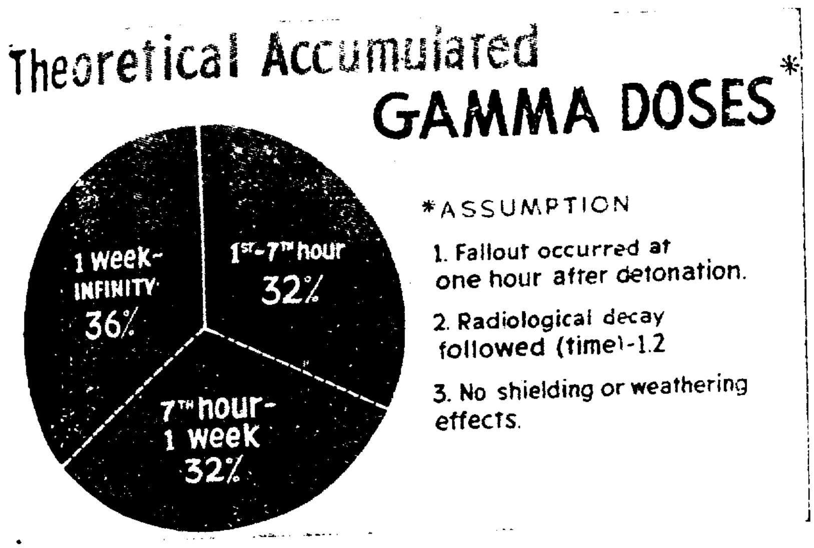

Theoretical Accumulated
GAMMA DOSES*
1st-7th hour
32%
7th hour-
1 week
32%
1 week-
INFINITY
36%
*ASSUMPTION
1. Fallout occurred at one hour after detonation.
2. Radiological decay followed (time)-1.2
3. No shielding or weathering effects.

FIGURE 4

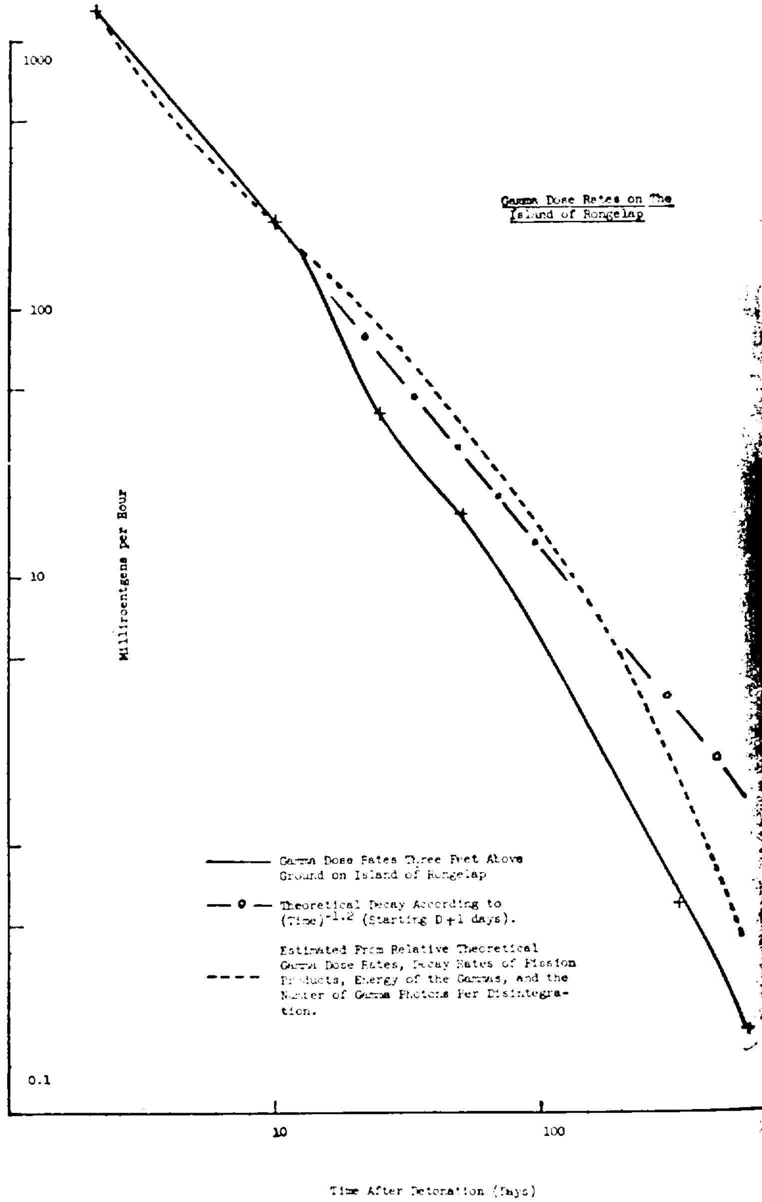

Gamma Dose Rates on The Island of Rongelap
1000
100
10
0.1
Millirroentgens per Hour
10
100
Time After Detonation (Days)
Gamma Dose Rates Three Feet Above Ground on Island of Rongelap
Theoretical Decay According to (Time)$^{-1.2}$ (Starting D+1 days).
Estimated From Relative Theoretical Gamma Dose Rates, Decay Rates of Fission Products, Energy of the Gammas, and the Number of Gamma Photons Per Disintegration.

FIGURE 5

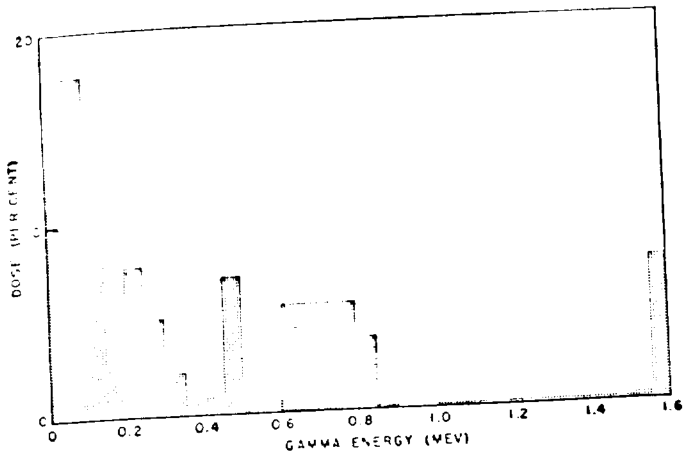
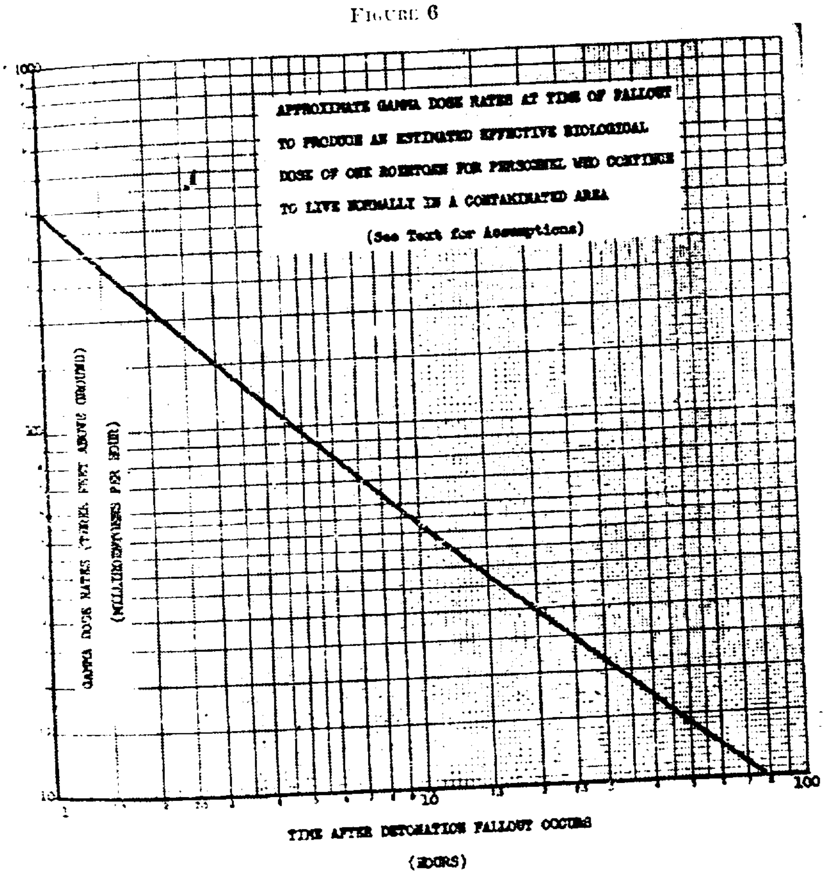


FIGURE 6



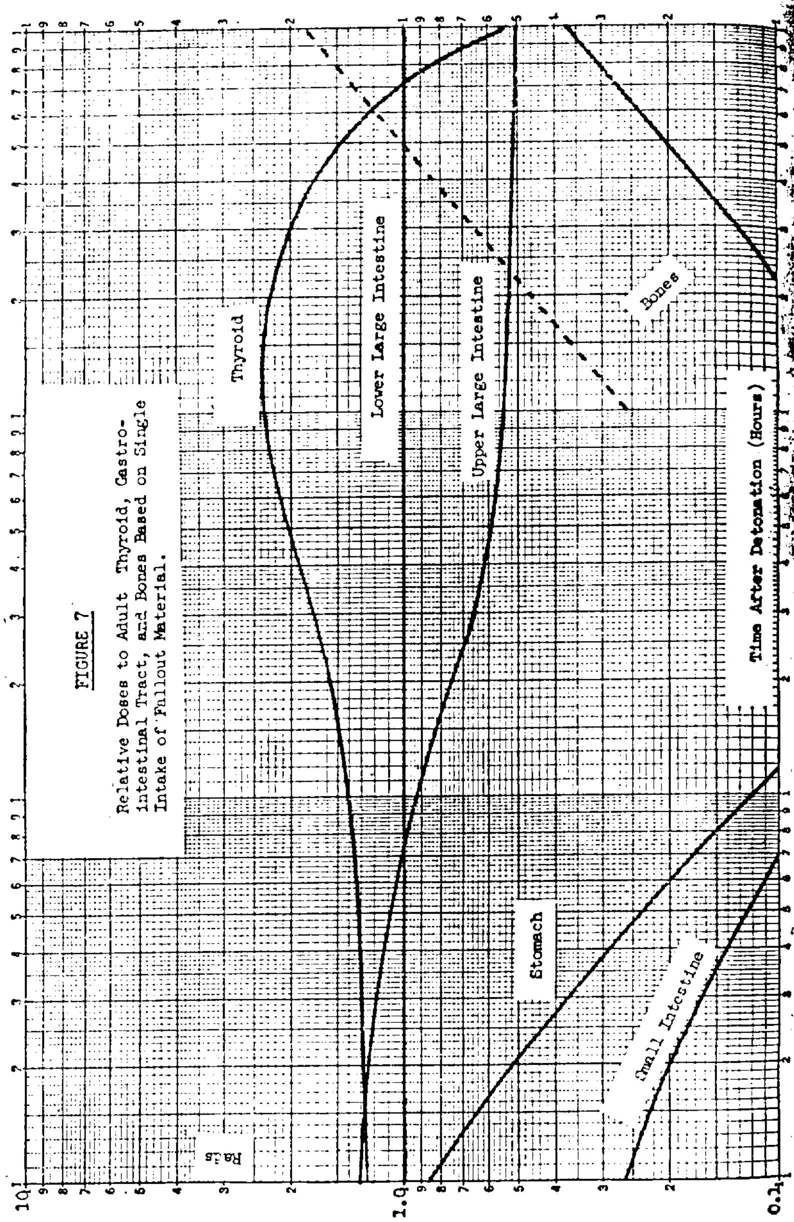


FIGURE 7

Relative Doses to Adult Thyroid, Gastro-intestinal Tract, and Bones Based on Single Intake of Fallout Material.

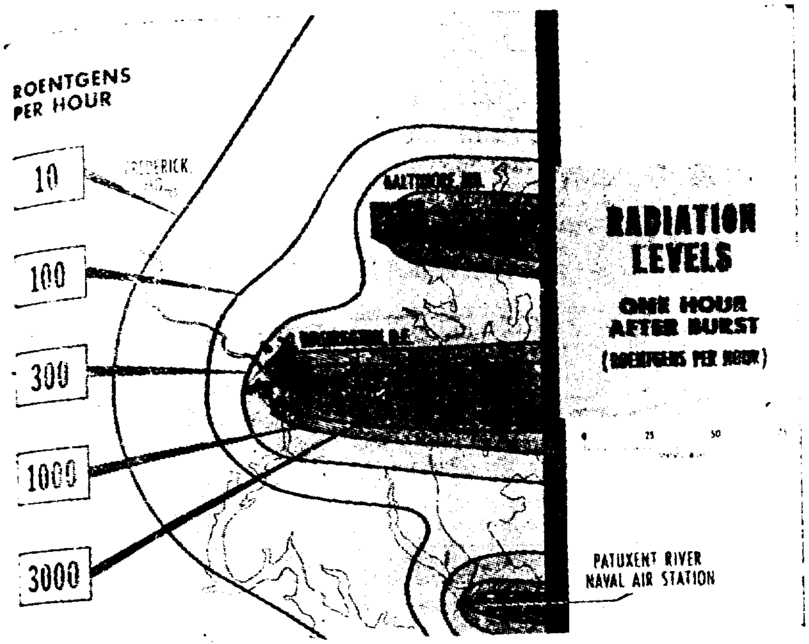


FIGURE 8

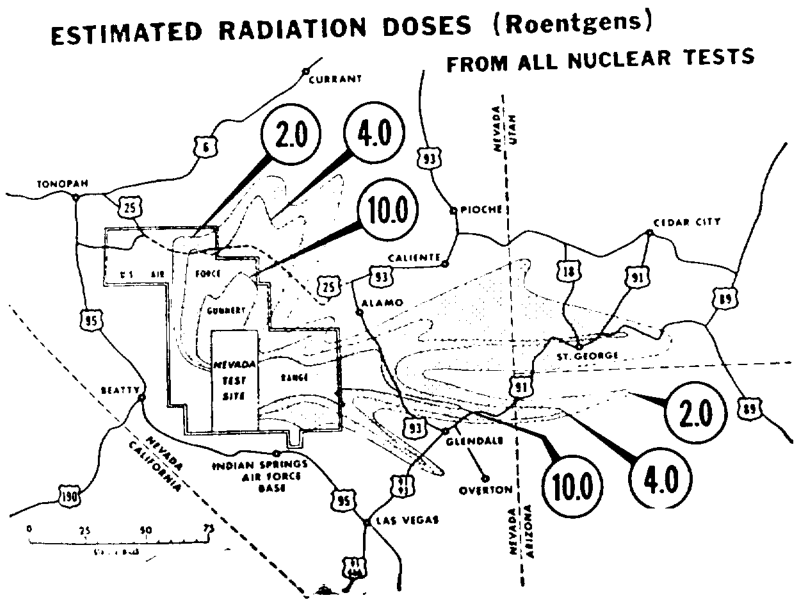


FIGURE 9

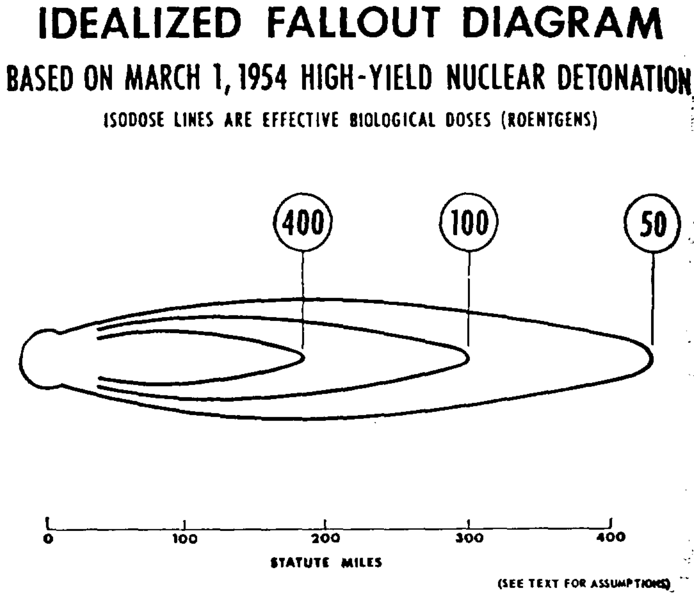


FIGURE 10. (See also table 3, p. 183.)

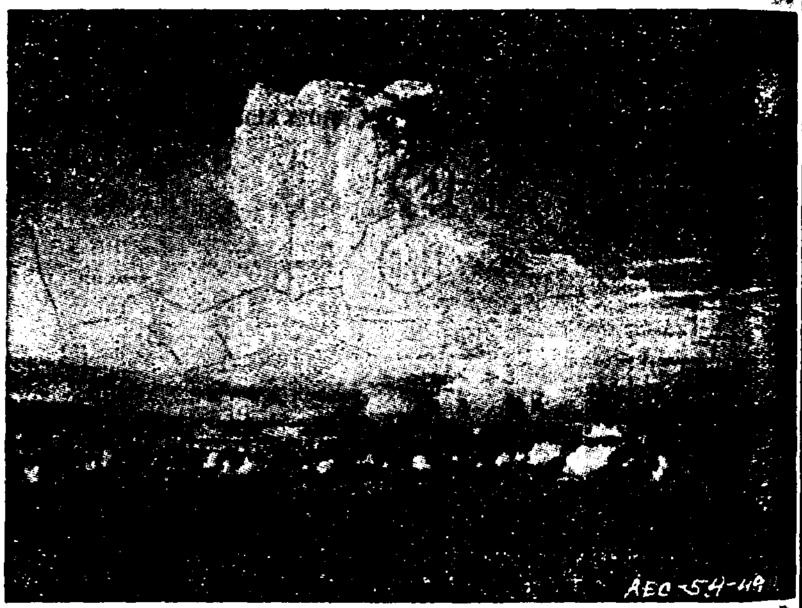


FIGURE 11.—Detonation during Operation Ivy; Fall 1952.

U. S. ATOMIC ENERGY COMMISSION,
Washington, D. C., March 20, 1957.

Hon. CHET HOLIFIELD,
Chairman, Military Operations Subcommittee,
Congress of the United States.

DEAR MR. HOLIFIELD: This is in reply to your letter of February 25, 1957, requesting "(a) the roentgen readings on Rongelap Atoll as of January 1, 1957; and (b) the roentgen readings as of the same date on the downwind island of ... Atoll where the fallout might be expected to simulate that of a suburban area of a big city." We do not have the data in the exact form which you requested, but are glad to give you the following information concerning radiation levels in these areas.

The last survey which we made of Rongelap was at the end of July 1956. This survey showed dose rates ranging from 0.2 to 0.5 milliroentgens per hour with an average of 0.4 milliroentgens per hour. Previous surveys had indicated that the dose rates in July 1956 would be aboout 0.1 milliroentgens per hour. The higher value found in July 1956 was undoubtedly due to the small additional fallout that occurred during Operation Redwing. If so, because of the relatively rapid decay of this fresh radioactive material we would expect that at the present time the radiation level is again in the neighborhood of 0.1 milliroentgen per hour or less. This is about one-half the currently recommended maximum permissible rate of exposure for general populations.

Gamma dose rates on the island of Rongelap observed in previous surveys are shown on the attached graph. The plotted points through which the solid line is drawn represent gamma dose rate readings at a point of 3 feet above the ground. The break in the curve between the 10th and 25th day was undoubtedly due to the first heavy rains that were known to have occurred after the detonation. Aside from this break you will note that the observed decrease of the gamma dose rate during the first 2 years follows rather closely values predicted from theoretical considerations.

The gamma dose rates on other islands in Rongelap Atoll have not been followed as closely but the data indicate similar *rates* of decay with the most heavily contaminated island being about 12 times higher activity than Rongelap Island. This was the uninhabited island of Naen on the northwestern rim of the atoll. The decay rates have not been similarly followed on the islands of Bikini because additional fallout occurred on these islands from subsequent detonations during Operation Castle and again during Operation Redwing. It would be expected, however, if the rates of decay for the March 1, 1954, fallout could have been followed, they would have been somewhat similar to those shown in the graph. (See p. 192.)

For any single fallout event, the degree of initial contamination in any area depends upon many variable factors. In general, the data suggest that after March 1954. Also plans are being developed for a continuing and long-range and the corresponding radiation dose rate in close-in areas (i. e., 10 to 20 miles) are not greatly higher than at 100 miles downwind, under wind conditions of some 15-20 miles per hour. However, it is important to realize that the radiation dose received by unprotected persons in the close-in areas is greater because they would receive a substantial portion of their total dose during the time required for the fallout to reach the more distant areas. You will recall that the fallout on the island of Rongelap started at about 5 hours following the detonation.

The Atomic Energy Commission is currently preparing a report summarizing the data from the surveys that have been made in the Marshall Islands since March 1954. Also plans are being developed for a continuing and long-range program of monitoring these areas.

Sincerely yours,

DAVID L. SHAW,
Assistant General Manager.

Dr. DUNNING. In describing and evaluating the effects of fallout, it is necessary to consider the characteristics of the radiations emitted from the material. These are of three types, as you learned yesterday: Gamma rays, beta particles, and alpha particles.

The gamma rays are the emissions of principal concern, because of their greater range, and we will speak primarily of them.

The gamma radiation dose that one may actually receive from fallout, and the biological effects are dependent upon five principal factors. Let us consider each of these 5 factors briefly, and then attempt to integrate them into 2 illustrative examples.

The first factor is radiological decay.

The decrease in radioactivity of fallout material roughly follows the relationship of time to the −1.2 power.

I have illustrated on the first chart the doses that might be accumulated if fallout were to occur 1 hour after detonation. If you were standing out of doors, fully exposed, from the first to the seventh hour after the detonation, one would accumulate 32 percent of the total possible exposure in that area. From the seventh hour to 1 week later, 32 percent more, and from 1 week to the full lifetime of the radioactive material, the other 36 percent. This is based on a 1-hour fallout. (See p. 191.)

If the fallout occurs at later times, then the exposures accumulate much less rapidly. In other words, it would take much more than the first 6 hours to accumulate the 32 percent of the total possible dose.

The second principal factor that determines doses and effects is weathering and shielding effects.

Obviously, these vary from time to time and place to place, so we cannot make any precise evaluation of them, but we can make some generalizations.

Based on data from the Pacific tests, especially the one of March 1954, we found that the dose rates on the islands were reduced by a factor of about two after the first heavy railfall; but after that the subsequent rainfalls did not seem to reduce these dose rates appreciably. However, there are good data lacking on the effects of rainfall on relatively heavy fallout patterns for large land masses having different soil characteristics, or on built-up areas.

The next chart summarizes some of the estimates of shielding that might be expected from different type structures. These are based principally upon theoretical calculations, since there are a paucity of field data. (See table 1, p. 182.)

In an ordinary 1-story frame house, such as many of us live in, on the first floor there would be about 50 percent as much exposure as there would be out of doors. In the basement, the center, about 10 percent as much as that out of doors; on the side of the basement less than 10 percent; in other words, better protective factors.

For a multistory reinforced concrete, on lower floors away from windows, a factor of 10; and for the basement we are again down to one-tenth of 1 percent of the out-of-doors exposure.

Likewise, with shelter equivalent to 3 feet of earth, we are down to one-tenth of 1 percent of the outdoor exposure.

Senator HICKENLOOPER. Mr. Chairman?

Representative HOLIFIELD. Senator Hickenlooper.

Senator HICKENLOOPER. May I ask about the building, the frame house. Does that contemplate all the windows closed, or does it contemplate free access of air? Or is it in the blast area? Or where are these houses located, for the record?

Dr. DUNNING. The assumption is made here that the windows are closed. If the windows and doors are open, this in itself makes little difference, but then, as you implied this will allow the radioactive material to drift into the house, and, of course, raise your level.

Representative HOLIFIELD. Then this would mean that large areas of land might remain unoccupied for a considerable number of months?

Dr. DUNNING. Yes. But I was about to mention that this is based on the assumption that people do nothing to protect themselves, and nothing to decontaminate the area; simply let it lie there and decay.

Representative HOLIFIELD. It is a very difficult job to decontaminate the large areas of the earth.

Dr. DUNNING. That is quite true. Probably one of the best procedures, if one can afford to do this, is merely to wait and let the activity decay away. But in this area of highest activity which would encompass, perhaps, a few thousand square miles, perhaps measures could be taken on decontamination which would not have to be done in the larger 25,000 square mile area.

Senator BRICKER. What processes of decontamination are available?

Dr. DUNNING. This is a whole subject in itself, sir. I will just briefly mention that the United States Naval Radiological Defense Laboratory in San Francisco have made considerable studies on this subject, and have proposed certain measures of decontaminating buildings and land areas. How effective they are I think is yet to be shown. There has been some experimentation, but I feel a great deal more needs to be done.

Chairman DURHAM. You are speaking primarily to gamma rays now; are you not?

Dr. DUNNING. Yes; this has been completely on gamma rays.

There are other types of rays. The beta rays are of concern, it appears, according to our present data, only when the fallout material comes directly on the skin and remains there for a period of time.

In the case of the fallout of the Marshallese, it was very illuminating to note that even a single layer of cotton clothing was enough to prevent serious beta dose to the skin, and where the fallout material did land on the skin and did remain there, such as in the folds of the neck and in the elbow, there were these so-called beta burns, burns of the skin from these beta rays. Yet, where they had the light clothing on, there were no burns. Nor were there any on even the lower part of the leg, but there were on the feet where again the material had been scuffed up from the ground.

Representative HOLIFIELD. Can you refresh the committee's memory on how many days later this exposure occurred, and how far the place was from the point of detonation?

Dr. DUNNING. The inhabitants of Rongelap Island were about 110 statute miles from the point of detonation. Some were evacuated at 36 hours, and some at about 48 hours after detonation. Upon evacuation, they took baths. Some of them did beforehand, and some of them not. It would appear that those who did take baths in the ocean did not get beta burns. It is merely a physical picture of moving the material from the body.

Representative HOLIFIELD. I referred to that specifically, and I am glad you answered the way you did, because this gives you a chance to answer also in regard to the Japanese fishermen on the *Lucky Dragon* as to how many days later it was they were supposed to have received their exposure.

Dr. DUNNING. They were generally in the same distance, only somewhat closer than the Rongelapese. The fallout occurred on them, and they did not wash in general. Most of the dose was delivered in the first few days, and so it is a question of getting it off and getting it off fast.

The next topic we will discuss is that of internal exposure which has been mentioned several times before this committee.

The principal hazards from intake of relatively large amounts of radioactive fallout for several weeks immediately following a nuclear detonation are doses one may get to the gastrointestinal tract, to the thyroid, and to the bones.

My written report to this committee considers in detail the amount of ingested fission product activity material required to produce certain radiation doses to these critical organs of the body, and the possible biological effects therefrom.

It is a somewhat long, complicated story, Mr. Chairman, and I would let it go at that, and quote one conclusion, and that is: If the degree of contamination of an area is such that the external gamma radiation may be accepted, for continuous occupancy, then probably the internal hazard would not deny this occupancy.

I think some folks get somewhat confused. They say: "Fine. I think I begin to understand the external doses, but should I drink this water? And should I eat this food?"

As I say, as an overall generalization, this conclusion would appear to be so, but like most of these it is tentative and awaits further information.

Representative HOLIFIELD. There is this one factor I think you will recognize: That in the ingestion of material from the secondary source of vegetables or milk, you would be ingesting the long-lifed element of strongtium 90, and not the comparatively short-lived gamma or beta rays.

Dr. DUNNING. That is correct, sir; and my conclusion took that into account.

Representative HOLIFIELD. Of course, while it might not be lethal, and would not be lethal in the quantities you speak of, it would be residual within the bones or the tissues of the body, and would be a permanent infestation, you might say.

Dr. DUNNING. That is correct. But then one must go from there to the next step, and say, "What is the actual dose delivered to the bones from this internally deposited material?" Because actually there is no significant difference between a roentgen of exposure, whether it comes from strontium 90 or from gamma rays, coming from material lying on the ground.

That is what I put into this conclusion when I said the amount of material that one gets into the body by eating food and drinking water in such an area would be acceptable in the sense that it would be far below lethal amounts. But I think we have to make a distinction in our mind here between peacetime tolerance levels and wartime. I do not have any specific number in my mind, but in these areas where we might permit occupancy in the case of warfare, they would probably accumulate internally deposited materials that would be in excess of our peacetime standards. I think we have to make this distinction.

Representative HOLIFIELD. Is there a distinction between an area that has a hundred roentgens of gamma radiation and its effect upon the body and, say, the ingestion of 5 or 10 roentgens which remain permanently in the bone now?

Dr. DUNNING. There is very little difference between a roentgen delivered from internal or external sources.

I think, in general, one can make the flat statement that a hundred roentgens, whether it comes from material on the ground or in material you eat, and that goes to the bones, is about the same.

Representative HOLIFIELD. It is a hundred roentgens, but it is not a deposit of strontium 90, which has a persistence over a period of 28 years, while your outside exposure, you might say, to gamma rays or beta rays, would be something that would be temporary in nature and would be subject to repair, where a permanent deposit in the bone marrow would be permanent as far as the half-life is concerned; and, therefore, it would be something that you could not get away from, you might say.

Dr. DUNNING. Yes; I understand. I just repeat that, if we forget the time factor for a moment and simply say that so many roentgens of exposure to the bone, it makes no difference whether you get the hundred roentgens from the gamma rays or from the material in the body. It stays there. Sure, it persists there. What I was saying, as long as it persists, we have the doses year by year by year, and if it all adds up to a hundred roentgens, this is no different, in a sense, from a hundred roentgens of gamma rays, except possibly for the time factor.

Representative HOLIFIELD. This is getting in pretty deep water for me. My thought was that you have a permanent localized area of radiation in the ingestion of strontium 90, where you would not necessarily have a localized concentration of it in the case of allover bodily exposure of a hundred roentgens.

Senator BRICKER. I think there is a misunderstanding generally about the amount of strontium 90 that can be put in the bones from ingestion, because there is only a small percentage of fallout of strontium 90 that goes to plantlife, and only a limited percentage of strontium 90 that goes to animal life, and only a little percentage of that which goes into milk or meat. I think it is something like 6 percent.

Dr. DUNNING. If I may move on, that was my next point here.

Again now we are thinking in terms of warfare, and not in terms of testing.

We have the situation of this March 1 shot, where we have a relatively heavy fallout from a high yield weapon that appeared on the islands in the Pacific. Since then, we have had 10 radiological and biological surveys of these islands. I thought the committee would be interested in a summation of those data, that is, what was the actual contamination of environment in terms of food supply.

I would like to preface by saying that any conclusions are tentative because there are many uncertain factors here, but at least the data suggests in terms of strontium 90 the activity in plantlife in the islands built up over 1 year, that is, it takes time for material to get into the soil, plantlife, and edible parts.

By using rough extrapolations, the data suggests that if plantlife had been growing in the area of heaviest contamination it might have contained 10,000 to 30,000 Sunshine units, at 1 year's time. The corresponding values for the soils are several times higher. Based on certain assumptions, these data suggest possible levels of strontium 90 in the bones of animals from continuous consumption of this food, of a few thousand to several thousand Sunshine units. Now the maximum permissible body burden for adult atomic-energy workers is equivalent to 1,000 Sunshine units.

There is some confirmatory evidence for this crude evaluation. A variety of native animals were left on the island of Rongelap after the fallout in March 1954. They were collected and sacrificed serially in time. Even after 2 years of continuous occupancy it was reported that there were no pathological changes that could be ascribed to radiation. Their bones contained from about 100 to a few hundred Sunshine units. Since the areas of highest contamination were about 10 to 14 times greater than Rongelap, an extrapolation would suggest values in the same range, that is, if animals had lived in the area of greatest contamination from this fallout, they might have accumulated from a few thousand to several thousand units, of strontium 90 in their bodies.

The Pacific island soils have higher calcium content than most soils in the United States, and, of course, there are differences in the type of plantlife and in the climate. However, theoretical calculations suggest that the same fallout in the United States might result in something like 100,000 Sunshine units in the soils of the United States with the highest contamination. Humans living exclusively off the foods grown in these soils might accumulate a body burden of strontium 90 of a few thousand to several thousand Sunshine units, keeping in mind that 1,000 is the maximum permissible body burden for atomic-energy workers.

Chairman DURHAM. Doctor, the effect of a hundred roentgens from the soil would be no more toxic than the 100 roentgens from the strontium; is that correct?

Dr. DUNNING. As far as the bones are concerned, it is correct. If you receive 100 roentgens from the gamma or strontium, it is essentially the same thing.

Chairman DURHAM. I was thinking of gamma rays.

Representative HOLIFIELD. Let me ask this question on that very point: If the 100 roentgens were ingested, would they not tend to go to certain organs of the body and have a concentrated effect, and, therefore, more of an effect upon, let us say, the liver or the spleen, or some other organ of the body that might be vital to the life of a man, than if the 100 roentgens were spread over the whole body?

Dr. DUNNING. If you could turn that around just a bit, Mr. Chairman. The way we compute it, we asked the question, How much material taken into the body will essentially result in 100 roentgens to the bones, to the liver, et cetera? We start the other way around from what you are saying. We simply ask how much material does one have to take in to end with a 100 roentgen dose. So we have reached our conclusions——

Representative HOLIFIELD. Again, are you not faced with the fact that you could not give a uniform dose of a hundred roentgens to every organ in the body, because some organs of the body—and I am speaking now in the case of ingestion of food or drink—some of the organs of the body would naturally process that, and it would be deposited in those organs rather than in the outside skin and toenails, and so forth.

Dr. DUNNING. That is correct. When we speak of external gamma, we mean essentially that each and every part of the body receives this 100 roentgens.

Representative HOLIFIELD. This I can understand, but I cannot understand how you can ingest contaminated foods or liquids and have it affect the body uniformly.

Dr. DUNNING. I did not mean to say that. If I did, it is incorrect.

Representative HOLIFIELD. You did not say it. I am saying it as a question or a statement for clarification.

Dr. DUNNING. You are quite correct.

Representative HOLIFIELD. Am I right in my supposition?

Dr. DUNNING. You are quite correct.

Chairman DURHAM. What we are saying, Doctor, whether it comes from Sunshine or whether it comes from strontium 90, that is, the gamma ray, it is no different as far as the effect of it, as if the same dose is taken.

Dr. DUNNING. That is correct, sir.

Lastly, then, I would like to mention briefly about the testing, and I do think we have to make a sharp demarcation in our minds that we have up to now been talking about more of a warfare situation. But intimately tied up with this is the testing.

Very extensive efforts are expended to protect the public in the planning of test nuclear detonations, and in the monitoring programs in operation during and between the test series. These are described in a detailed written report to the committee previously.

Since 1951, the United States has conducted 11 series of nuclear tests, 5 at the Nevada test site, and 6 at the Eniwetok Proving Ground for a total of more than 63 test detonations. A sixth series is currently underway at Nevada. So I understood by the report this morning.

The major effects near the testing sites of the fallout was on the inhabitants of some of the Marshall Islands in March 1954, which will be discussed by others, and fallout on the 23 Japanese fishermen. Worldwide effects will be discussed by others.

Since the committee manifested an interest yesterday in the fallout nearby, especially in Nevada, I do have a chart that may be of interest to you. This is our best estimate of exposures in areas around the Nevada test site. The units are roentgens of gamma exposure. They are based on certain assumptions, one of which is that the total dose is this [indicating] if one continues to live there indefinitely. (See bottom of p. 195.)

With those numbers before you, I would like to recall to your mind the recommendations of the National Committee on Radiation Protection and Measurement, and the recommendations of the National Academy of Sciences, which, in lay language, sort of lays the ground rules for our permissible exposures.

Both committees—expressed in somewhat different units, both committees said, in essence, that for individual exposures the maximum permissible amount should be 50 roentgens up to age 30.

Representative HOLIFIELD. At this point, it might be well for you to explain the term "Sunshine unit" in relation to roentgen. Is that not an occupational unit of measurement rather than a general population unit of measurement?

Question. How constant is the relation between air dose and the biologically effective dose in view of the known gamma radiation energy changes with time?

Answer. It is correct that the energy spectra of gamma radiation dose changes with time and thus will affect the dose distribution within the body and the energy delivered to different parts of the body. Further, the energy spectra at any one time is quite complex, consisting of photons over a wide range of energies, except for long times after a detonation when only a relatively few isotopes remain, such as cesium 137. All of these do complicate the problem of estimating the biological effects. However, there are other variables, such as weathering and shielding and decay constants that have as great or probably greater influence in determining the effective biological dose accumulated.

Question. Compare the numbers derived from the $(\text{time})^{-1.2}$ law decay with that derived from the application of the known gamma emissions from the fission products.

Answer. The relation of $(\text{time})^{-1.2}$ was intended to apply to the actual disintegrations of the atom. We have accepted the rate of beta emissions as closely approximating the actual disintegrations of the atom. However, the ratio of gamma photons emissions to beta emissions varies with time (as does the gamma energies) so that the actual decay of *gamma dose rates* can deviate from the $(\text{time})^{-1.2}$. This deviation probably is not very great until several months after the detonation, when theoretical calculations indicate that the decay is significantly greater than $(\text{time})^{-1.2}$. This is shown in figure 4 of my written report. Of course, presence of any *induced* activity can also result in a departure from $(\text{time})^{-1.2}$.

Discussion of Radiological Safety Criteria and Procedures for Public Protection at the Nevada Test Site *

Gordon M. Dunning, United States Atomic Energy Commission, Division of Biology and Medicine, Washington, D. C., February 1955

Introduction

The criteria and procedures set forth in the following paragraphs were established after full consideration for protecting the health and welfare of the public, both in terms of radiological exposure as well as possible hazards, hardships, or inconveniences resulting from disruption of normal activities. Criteria are established as guides for the test organization in determining whether any special actions should be taken to protect the public.

With improved methods of predicting fallout and with the use of higher towers for detonating the nuclear devices, it is expected that fallout in populated areas from future tests at the Nevada test site will be less than the highest amounts which have occurred in the past.

Two basic assumptions are made in this report:

(*a*) It is the responsibility of the Division of Biology and Medicine to establish such criteria and procedures for the Atomic Energy Commission as deemed necessary to protect the health and welfare of the general population from consequencies of weapons tests conducted at the Nevada test site.

(*b*) The operational procedures adopted for meeting these criteria and procedures shall be the responsibility of the test manager, as directed by the Division of Military Application, with the technical guidance of the Division of Biology and Medicine.

The following criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified herein.

Criteria I. Evacuation

Introduction

The decision to evacuate a community is critical for two principal reasons: One, presumably there might be a health hazard if the personnel were allowed

* This document was based on data and thinking of nearly 2 years ago. Since then the criteria have been revised and are reproduced on pp. 248 through 258. It is planned to revise further these criteria based on additional data and experience gained from operation PLUMBBOB (1957 test series at the Nevada test site).

to remain. Two, there is always an element of danger and/or hardship to personnel involved in such an emergency measure.

It is recognized that extenuating circumstances may accompany any situation where conditions indicate evacuation as a mode of action. The size of the community, areas, and accommodations available for the evacuees, means of transportation and routes of evacuation, disposition of ambulatory cases, protection of the property left behind, and many other factors may enter into the decision relative to evacuation. Further, it is recognized that, under certain conditions, the evacuation of a community might not only prove rather ineffectual but could result in more radiation exposure than if the population remained in place unless the situation be adequately evaluated. A blanket evaluation cannot be made in advance: each situation can be unique. The following criteria therefore are suggested as guides in assessing the possible radiological hazards; the final decision must be made on the basis of all relevant factors known at the time.

Criteria

Table I–a summarizes the radiological criteria to be used in evaluating the feasibility of evacuation.

TABLE I–A.—*Radiological criteria for evaluating feasibility of evacuation*

Effective biological dose [1] calculated to be delivered in a 1-year period following fallout	Minimum effective biological dose that must be saved by act of evacuation (otherwise evacuation will not be indicated)
Up to 30 roentgens	No evacuation indicated.
30 to 50 roentgens	15 roentgens.
50 roentgens and higher	Evacuation indicated without regard to quantity of dose that might be saved.

[1] The "effective biological dose" is an estimate of a biological "damage" dose, taking into account the length of time for delivery of a given dose, and the reduction of dose due to (a) shielding afforded by buildings and (b) the process of weathering.

The rationale for table I–a is as follows: The total effective biological dose that would be received if evacuation were not ordered is obviously a determining factor. Another consideration is the fact that such an action as evacuation could be dangerous to the individuals and could also possibly be detrimental to a very necessary national effort of weapons development. One must then ask, "Just how much will be gained (radiation dose saved) by evacuation?" Estimates of these two variables are indicated in table I–a. Thus, a populace may receive up to a calculated 30 roentgen effective biological dose in 1 year without indicating evacuation; from 30 to 50 roentgens, evacuation would be considered only if at least 15 roentgens could be saved by such action; and at 50 roentgens or higher evacuation would be indicated without regard to the possible savings in radiation dose.

In making a rough estimate of radiation doses, one may calculate a theoretical maximum infinity gamma dose and then arbitrarily divide by some number, such as 2, for an estimate of dose actually received. Whereas this may be satisfactory as a first approximation, a more accurate estimate should be attempted, especially when dealing with doses that might constitute a health hazard.

Owing to the necessity of making early measurements and decisions, it is to be expected that dose-rate readings, taken with survey meters, will be available evidence at the times of concern. Table I–b summarizes the parameters considered in estimating an effective biological dose based on dose-rate readings.

TABLE I-B.—*Predicting effective biological doses from dose-rate readings*

	A Theoretical maximum dose (based on best estimated rate of decay)	B Biological factor	C Attenuation and weathering factor	D Effective biological dose factor (column B×C)	E Effective biological dose (column A×D)
From time of fallout until time of evacuation	----------	1/1	1/2	1/2	----------
From time of evacuation to time of return [1]	----------	3/4	3/4	[2] 1/2	----------
From time of return to a time 15 days after initial fallout [3]	----------	3/4	3/4	[2] 1/2	----------
From 15 days until 1 year after initial fallout	----------	2/3	1/2	1/3	----------
Total	----------	----------	----------	----------	----------

[1] This estimate is based on the concept that if evacuation were not accomplished, then a certain radiation dose would be accumulated over the period of time selected. This time period also represents the radiation dose saved if evacuation were accomplished.

[2] The value of 9/16 has been rounded off to 1/2.

[3] This assumes that the time of return occurs before 15 days. A period of 15 days was selected to provide a dividing point between the time of initial exposure from fallout to a time 1 year later. The 15 days has no unique significance other than providing a basis on which to estimate the biological factor.

At a later time after fallout, better estimates of radiation doses received may be obtained from film-badge readings or dosimeters. If these film badges or dosimeters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurate account of the radiation dose received, then the values recorded on the film badge or dosimeter may be accepted with a correction factor of 3/4 to account for the difference between the dose received by the film badge or dosimeter (including back scatter) and that received at the tissue depth of five centimeters. Table I-c may be used in estimating the effective biological dose from film badge or dosimeter readings.

TABLE I-C

	A Film badge reading	B Biological factor	C Film badge or dosimeter correction	D Effective biological dose factor (column B×C)	E Effective biological dose (column A×D)
From time of fallout until time of evacuation	----------	1/1	3/4	3/4	----------
From time of return to 15 days after initial fallout	----------	3/4	3/4	[1] 1/2	----------
From 15 days until 1 year after initial fallout	----------	2/3	3/4	1/2	----------
Total	----------	----------	----------	----------	----------

[1] The value of 9/16 has been rounded off to 1/2.

Discussion of the biological factor.—As longer periods of time are involved in the delivery of a given radiation dose, lesser biological effects may be expected. From the time of fallout until the time of evacuation probably will be a matter of hours, which has been considered essentially an instantaneous dose, that is, the biological dose factor is 1/1. From the time evacuation could be accomplished to time of return probably would be a matter of several days, so the biological factor has been estimated at 3/4. From 15 days after fallout until 1 year later is essentially a duration of 1 year, so the biological factor has been estimated at 2/3. It will be noted there is no calculation after 1 year, because it is expected under actual conditions of radiological decay and weathering that probably no significant dose will be delivered after a year's time in populated areas around the Nevada test site.

It is recognized that the precise quantities suggested for the biological factor cannot be supported by conclusive evidence. It is reasonable to expect that the delivery of a given radiation dose over a period of many days will have less *cting effective biological doses from dose-rate readings*

	A	B	C	D	E
	Theoretical maximum dose (based on best estimated rate of decay)	Biological factor	Attenuation and weathering factor	Effective biological dose factor (column B×C)	Effe[ctive] biolo[gical] do[se] (col[umn] A×[D])
ne of evacuation	----------	1/1	1/2	1/2	
me of return [1]	----------	3/4	3/4	[2] 1/2	
ne 15 days after initial	----------	3/4	3/4	[2] 1/2	
er initial fallout	----------	2/3	1/2	1/3	
----------	----------	----------	----------	----------	

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rounded off to 1/2.
e of return occurs before 15 days. A period of 15 days was selected to prov[ide] ... ime of initial exposure from fallout to a time 1 year later. The 15 days has ... providing a basis on which to estimate the biological factor.

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TABLE I–c

	A	B	C	D	E
	Film badge reading	Biological factor	Film badge or dosimeter correction	Effective biological dose factor (column B×C)	Effective biological dose (column A×D)
e of evacuation	----------	1/1	3/4	3/4	
s after initial fallout	----------	3/4	3/4	[1] 1/2	
r initial fallout	----------	2/3	3/4	1/2	
----------	----------	----------	----------	----------	

rounded off to 1/2.

logical factor.—As longer periods of time are involved ... radiation dose, lesser biological effects may be expected ... t until the time of evacuation probably will be a matter of ... considered essentially an instantaneous dose, that is, the ... s 1/1. From the time evacuation could be accomplished ... tbly would be a matter of several days, so the biological ... ed at 3/4. From 15 days after fallout until 1 year later ... n of 1 year, so the biological factor has been estimated at ... here is no calculation after 1 year, because it is expected ... s of radiological decay and weathering that probably no ... delivered after a year's time in populated areas around ...

the precise quantities suggested for the biological factor ... conclusive evidence. It is reasonable to expect that the ... liation dose over a period of many days will have less

...gical effectiveness than an instantaneous one (neglecting genetic effects) and ... the extension of the period to essentially 1 year should yield a still lower ...gical factor. One piece of supportive evidence is the work of Strandgvist,[1] ...re X-ray doses to the skin were factionated into daily amounts, and the ...gical effects compared to a one-treatment dose. A log-log plot of total doses ...us days after initial treatment yielded straight lines. For example, the curve ... skin necrosis indicated a ratio of 3,000/6,700 roentgens for a 1-treatment ...sus 15 daily equally *fractionated* doses. Of course, daily radiation doses re...ed from fallout are not equally fractionated, so that the ratio would be in the ...tion of unity. Day-by-day doses delivered from fallout from the 15th day ... 1 year are more nearly equivalent *than at early times* (ignoring the weather...g factor). Strandgvist data do not extend beyond 40 days and it is questionable ... extrapolate his data in an attempt to derive a similar ratio as above based on ...ear, since other uncertainties are so great, that is, *effects of weathering* as ...ting the rate of dose delivery, and so forth. The ratio would presumably ... farther from unity than for a 15-day period. The skin is a relatively rapidly ...aired organ and thus may tend to overemphasize the effects of fractionation ...n considering whole-body gamma doses.[2]

Cronkite reports:[3]

"In the dog, with cobalt gamma rays, the dose that will kill 50 percent of the ...s in a 30-day period when delivered in a single dose at roughly 15 roentgens ... minute is approximately 275 roentgens. After this dose of radiation the ...mals become ill within a period of 7 to 10 days and deaths occur between ...8th and 25th day. Hemorrhage, infections, and profound anemia are prev...ent. If the dose is decreased to 100 roentgens per day given over a 14-hour ...od, the lethal dose is increased to 600 to 800 roentgens. Under both condi...s, the animals die in approximately the same period of time with identical ...nifestations. If the exposure is dropped to 25 *roentgens per day* given over ... 14-hour period, the lethal dose is then increased to well over 1,200 roentgen, ...d the symptoms and findings are changed."

...ne problem in such experiments is the evaluation of possibility *that the ani*...s may be virtually dead while the exposures are continued. This might be ...strated in experiments using the burro where the daily doses of 400, 200, ... 100 roentgens given to 3 separate groups required 3,600 to 4,000, 2,800 to ...00 and 2,000 to 2,600 total roentgens, respectively, for 100 percent lethality.[4]

Experimental data reported by Boche[5] are summarized below.

Number of days	Dose per day (roentgens)	Dose per week (roentgens)	Survival time (weeks)	Total dose (roentgens)
----------	10	60	24	1,440
----------	6	36	83	2,988

...—Un... ...ely normal survival times were not given nor were the ages of the animals (dogs).

Blair[6] has taken the two points from Boche's data, inserted these into his ...air's) equation relating reparable and irreparable damage. The ratio of in...taneous dose to 15-day dose is 350/450 or 0.78, and for 4 months' dose about ... 525 or 0.67.

Blair suggests that "the points are too few to determine the constants (of ...equation) with any accuracy but should at least be in the proper range." ...ever, the constants of his equation have checked well with more extensive ... on other animals. His equations indicate that the rate of recovery of ...rable injury is fastest in the mouse (of the types of mammals selected), ... one-half as fast in the rat, and about one-seventh as fast in the guinea

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...vert, Rolf M. The Tolerance Dose and the Prevention of Injuries caused by Ionizing ...tions. British Journal of Radiology, vol. XX, No. 236, August 1947.
...e added ...
Medical Aspects of Radiological Defense. Cronkite, E. P. Lecture to Federal Civil ...se Administration, Regional Conference of Northeastern States of Radiological and ...ical Defense, New York City, October 22, 1953.
... Response of the Burro to *100 Roentgens Fractional Whole-Body Gamma* ... Haley, T. J., et al. June 10, 1954. Unclassified.
... Observations on Populations of Animals Exposed to Chronic Roentgen ... Boche, R. D. 1947. Unclassified.
... A Formulation of the Injury, Life Span, Dose Relations For Ionizing Radia... ...ations to the Guinea Pig, Rat, and Dog. Blair, H. A. July 3, 1952.

pig and dog, but as Blair pointed out, the reaction of the dog is more representative of the larger, longer lived animals.

Discussion of the attenuation and weathering factor.—From the time of fallout until the time of evacuation it is expected that personnel will be kept indoors. (See criteria II.) Major losses due to weathering cannot be relied upon during this period, so that the estimated factor is 1/2. From the time evacuation could have been accomplished until the time of estimated return it is assumed that personnel will be indoors aboout half of each 24 hours and that major losses due to weathering cannot be relied upon. The overall factor is thus 3/4.

The same reasoning applies to the third period of time, i. e., from assumed time of return to 15 days after fallout.

From 15 days after fallout until 1 year later it is estimated that the attenuation due to buildings and the effects of weathering will yield an overall factor of 1/2.

Dose-rate readings have been taken with survey meters outside and inside of houses around the Nevada test site after fallout occurred. The ratio of readings varied with the type of construction of the house and with the location within the building. Generally, the ratio of readings outside to inside a frame house was about 2/1 with a somewhat greater difference for masonry construction. A limited number of film badges were placed outside and inside of some houses during Tumbler-Snapper and also Upshot-Knothole. In the first case, the difference in total doses was again 2 to 1 or greater, but during Upshot-Knothole only about a 20 percent difference was noted. In fact, in one case during Upshot-Knothole the film badge inside read higher than outside. The differences between these experimental data will have to be investigated during future operations.

The very nature of the weathering factor makes this a difficult paremeter to evaluate. The probability of occurrence of precipitation and/or winds and to what degree has to be estimated, as well as their effects on radiation levels. Leaching effects were studied on soils about 130 miles from ground zero where fallout had occurred during Upshot-Knothole. Dose-rate readings were insignificantly lower than those predicted by radiological decay according to $t^{-1.2}$ after a period of more than 1 year. One example of the effects of winds was observed during Upshot-Knothole. The fallout from the March 17, 1953, detonation was in a long narrow pattern to the east of ground zero. The second day after a fallout a rather strong surface wind blew almost at right angles across the area, for about a period of a day. Dose-rate readings were taken on the first and fourth days at the same locations and then were compared. The fourth day dose rates were less, by factors of 3 to 6, than those to be expected from the first day's readings, based on rate of decay of $t^{-1.2}$. (Other fallout measurements indicated that the rate of decay of this fallout material was not significantly different from $t^{-1.2}$.) Because of the physical conditions described above, these reductions in contamination probably are near the upper limit to be expected from wind.

Operational feasibility of criteria

It is not the intent here to discuss operational procedures, but it should be indicated that the computing of radiation doses as recommended in criteria I is a not too difficult task. If one assumes a $t^{-1.2}$ rate of decay as a first approximation, then a single graph of dose rates versus times after detonation can be constructed that will represent a 30 roentgen effective biological dose for 1 year. An additional family of curves can be made that will provide the answers to the parameters of how much time would be available before evacuation and of how long a time personnel would have to remain out of the radiation area in order to provide for a savings of at least 15 roentgens.

The highest whole-body gamma dose recorded for any locality where personnel were present outside the Nevada test site was at Riverside Cabins, Nevada (about 15 people), following shot No. 7 of Upshot-Knothole. The maximum theoretical infinity gamma dose was estimated to be 12 to 15 roentgens.

CRITERIA II. PERSONNEL REMAINING INDOORS

When the gamma dose rate reading as measured by a survey meter held 3 feet above the ground reaches the values given in graph II at the times indicated, it is recommended that personnel shall be requested to remain indoors with windows

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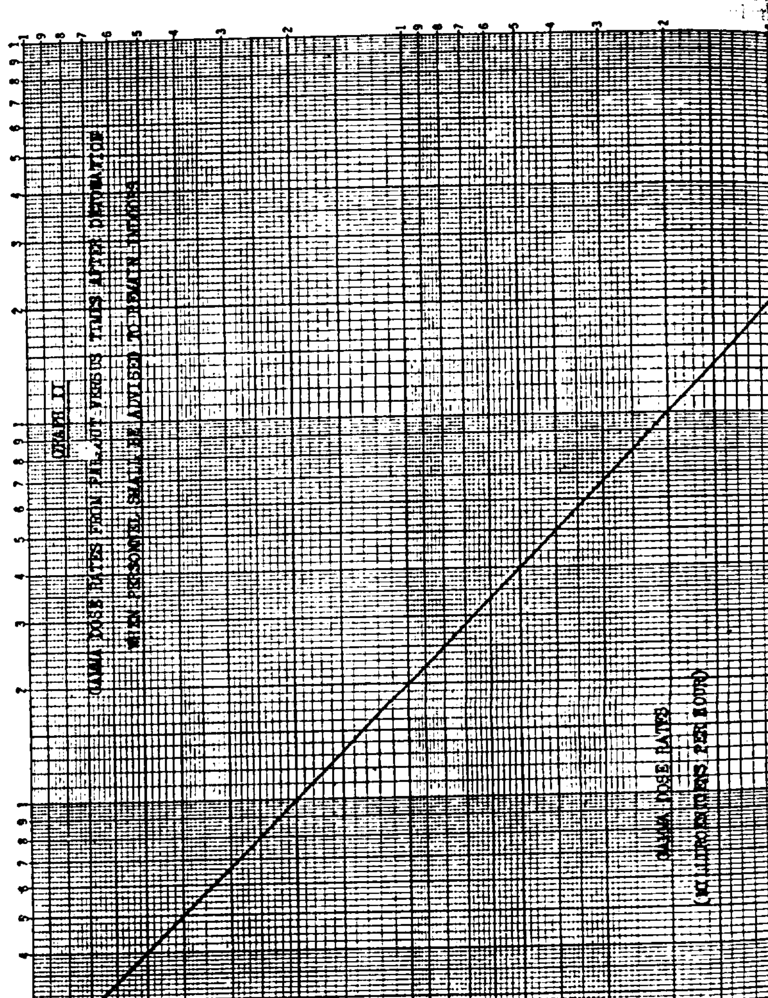
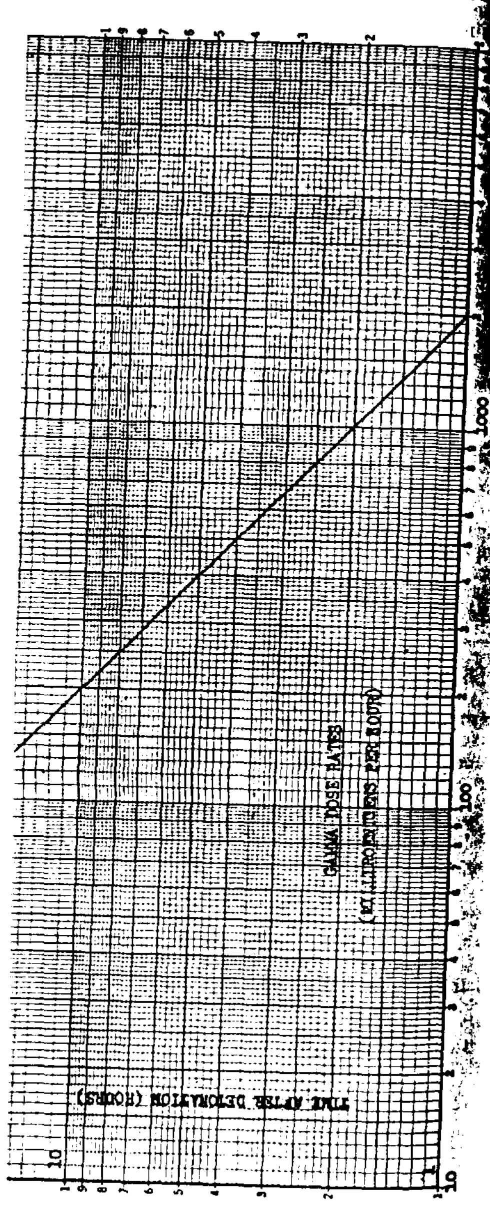
and doors closed. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

In the event that there be convincing evidence that the radiation levels given in the graph will be reached, it is recommended that personnel be requested to remain indoors before fallout occurs or before the radiation levels equal those in graph II. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

It is recommended that people who had been out-of-doors during fallout of the above magnitude or greater be advised to change clothing and to bathe. The clothing may be cleaned by normal means. While bathing, special attention should be paid to the hair and any exposed parts of the body.

In the event that the monitoring takes place after the fallout has occurred, and extrapolation of the dose-rate readings equals or exceeds those in graph II at the estimated time of fallout, then it is recommended that the same advice be given as in the preceding paragraph.


GRAPH II
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION
WHEN PERSONNEL SHALL BE ADVISED TO REMAIN INDOORS
GAMMA DOSE RATES
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
100
10
1



Discussion

The action of requesting personnel to remain indoors is predicated on the principle that the radiation levels are below those established for evacuation and that this action could reduce the amount of contamination of personnel and reduce somewhat the whole-body gamma dose. (See appendix A for estimates of reduction in whole-body gamma dose.) The actual "savings" healthwise have to be balanced against possible adverse public reaction.

The principal gain in requesting personnel to remain indoors is to prevent or reduce the amount of atomic debris that may actually fall on the body or clothing. Since the peak of fallout usually occurs shortly after the start of fallout, it is important that prompt decisions and actions be taken. Thus, by necessity, the most practical criteria upon which to base a decision are gamma dose rate readings, which are in turn related to the amount of fallout.

Beta dose to skin.—The most immediate solution might be to establish lower permitted dose rate levels at later times after detonation. However, if a series of dose rates are established for increasing times after detonation so that their relationship follows $t^{-1.2}$, then the doses delivered in X hours (before the material is washed off) will be greater for earlier times after detonation. If one were sure of the time that the fallout material was to remain in place, then a scale of dose rates versus time after detonation could be made to yield the same total dose over the X hours. Since there is obviously no set time period for duration of contact that would be valid for all cases, one might assume the worst case where the material remains in place until its activity has decayed to an insignificant level. Dose rates could then be approximated, to yield a given infinity dose, by:

$$D=5At \quad \text{where: } D=\text{infinity dose; } A=\text{dose rate at time "t".}$$

If the above discussion is accepted, then the remaining question is to set the infinity dose. Here, we must be clear that whereas the measurements taken by the monitors, and the data upon which action will be decided will be gamma dose-rate readings, the point of principal concern is the beta dose delivered to the basal layer of the epidermis (assumed as 7 milligrams per square centimeter). The ratio of emission of beta to gamma is a function of time after detonation and follows no simple relationship. Further, this ratio at any given time after detonation has not been firmly established. One report suggests the following data:

Time after detonation:	*Beta/gamma*
72 hours	157/1
168 hours	156/1

These data were obtained from a cloud sample rather than actual fallout material, and were a measure of surface dose on a plaque using a "dosimeter type beta-ray surface ionization chamber."

The method of collection suggests the possibility that the thickness of material on the plaques may be less than that to be expected from the amount of fallout that would be of concern when estimating probabilities of beta burns. This would result in a different angular distribution of the betas influencing the beta dose rate in the direction of a higher value for the plaques.

Another report indicates a beta to gamma ratio of 130 to 1 based on theoretical computations. A third report suggests a radically lower ratio; however, there may be some doubt as to its conclusions since the ionization chamber, used to measure gammas only, had a wall thickness of 1 mm. of bakelite which "* * * excluded a small part of the total gamma dose present, as well as a large, but unknown, fraction of the beta." (The range of 0.35 Mev. betas is about 100 mg./cm.² or approximately 1 mm. of bakelite.) For our discussion here, we will assume a *surface* beta to gamma ratio of 150 to 1.

In estimating the beta dose to the basal layer of the epidermis, one may to the work of Henriques.[7] He exposed the skin of Chester White pigs to pla containing different radioisotopes. Pertinent data are abstracted as follow

Isotope	Energy	Surface dose required to produce recognizable transepidermal injury (roentgen-equivalent-beta)	Estim amoun radiation penetrate to a dep 0.09 mm. gen-equi beta
Yttrium 91	1.53	1,500	[illegible]
Strontium 90	.61	1,500	[illegible]
Ytrrium 90	2.20		[illegible]

The average maximum energy of the beta particles from fallout mate varies with time but will be assumed to be roughly comparable, in respec depth dose, to yttrium 91 or Sr-90—Y-90. Since the gamma dose at a dep of 7 mg./cm.^{2} would not be significantly different from the surface gamma do the ratio of 130 to 1 for beta-gamma will be assumed at the basal layer of t epidermis.

(One experiment with sheep, using Sr-90—Y-90 plaques, showed that 2,0 reps at the plaques' surface produced ulceration in 1 but not another of 2 sheep On the other hand, 1,000 rads delivered to tissue depth of 7 mg./cm.^{2} from P^{32} 1-inch diameter disk (type of animal not stated) produced tanning, prolonge erythema, and desquamation.)

It is to be remembered that the above discussion was first based on surfac gamma dose rates whereas the monitors will be making their gamma measure ments at a height of 3 feet. Past field experience has indicated that the gamm reading from ionization-type survey meters at ground level is about 50 percen higher than at 3 feet. Therefore, if it be assumed that a ground level gamm reading of a survey meter is equivalent to a surface dose rate, the ratio of bet dose rate at 7 mg./cm.^{2} to gamma dose rate at *3 feet* is about 200 to 1.

Another approach to estimating the ratio of beta dose rate at 7 mg./cm.^{2} t gamma dose rate at 3 feet is as follows: Assuming a uniform distribution o 1.0 megacurie per square mile of gamma activity, the dose rate reading fro an infinite field is about 4.1 roentgens per hour.[8] Calculations given in appendi B indicate that a like concentration of fallout material will produce about 4 reps per hour at 7 mg./cm.^{2} This suggests a beta to gamma ratio of about 1 to 1 which is about a factor of 2 lower than the first approach. Added suppo to this latter method of estimating beta doses is found in appendix C.

Such considerations may be fraught with pitfalls. For example, the abov discussion implies a uniform distribution of fallout material. Obviously this i not correct, but how far this deviates from the facts and to what extent thi influences the results is difficult to assess. Calculations indicate that the pro duction of recognizable beta burns from a single particle requires a high speci activity. (See criteria III for discussion.) It may well be, however, that th particles of fallout are close enough to have overlapping of radiation fields an thus require significantly lower specific activity of the particles to produce be burns. This hypothesis has support in that even the most superficial beta bur of the natives exposed to fallout following the March 1, 1954, detonation showe a general area affected rather than small individual spots. On the other han the cattle and horses exposed near the Nevada test site showed burns over are only about the size of a quarter. Even though these may not have been pro duced by single particles, they do represent less of an area effect than suggeste for the natives. Also, radioautographs of the fallout in areas outside the Nevad test site suggest the occurrence of individual particles with nonoverlapping o radiation fields. However, in nearby areas where the fallout was relativel heavy, there was a definite overlapping of the fields.

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[7] Effect of Beta Rays on the Skin as a Function of the Energy, Intensity, and Duratio of Radiation. Henriques, F. W. Laboratory Investigation. Vol. 1, No. 2. Summer 1952

[8] Comparative Study of Experimentally Produced Beta Lesions and Skin Lesions i Utah Range Sheep. Lushbaugh, C. E., Spalding, J. F., and Hale, D. B. LASL, Novembe 30, 1955. (Unclassified.)

[9] Effects of Atomic Weapons. 1950.

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Isotope	Energy	Surface dose required to produce recognizable trans-epidermal injury (roentgen-equivalent-beta)	Estimated amount of radiation that penetrated skin to a depth of 0.09 mm. (roentgen-equivalent-beta)
----------------	1.53	1,600	[illegible]
----------------	.61	1,500	[illegible]
----------------	2.20		[illegible]

maximum energy of the beta particles from fallout material e but will be assumed to be roughly comparable, in respect to ttrium 91 or Sr-90—Y-90. Since the gamma dose at a depth ould not be significantly different from the surface gamma dose to 1 for beta-gamma will be assumed at the basal layer of the

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tudy of Experimentally Produced Beta Lesions and Skin Lesions in Lushbaugh, C. E., Spalding, J. F., and Hale, D. B. LASL, November
le Weapons. 1950.

With our present knowledge it should be stated that due to the particulate nature of fallout it would not be possible to establish reasonable and operationally workable criteria that at the same time would guarantee that there *never* would be an occurrence of a beta burn.

If one were to accept the assumed beta to gamma dose rates of about 100–200 to 1 (measured under the conditions given above), this might mean an infinity beta dose of 1,000 to 2,000 reps to the basal layer of the epidermis when the whole body infinity gamma dose was 10 roentgens. Of course, the fallout material may be removed before the infinity dose is delivered; yet, on the other hand, it is not improbable that it could remain in the hair for essentially this length of time. In the case of a 1-hour fallout, almost one-half of the dose would be delivered in the next 24 hours.

The efficiency of a surface for collecting and holding the fallout material is important. It is not surprising that the highest dose rate readings as well as biological effects were noted on the hair of the natives and also on parts of the exposed body where perspiration was present. Further, it was observed that even one layer of light cotton material was sufficient to protect against beta skin damage in most cases.[10] This was due probably not to the relatively small attenuation of the betas by the clothing but rather to the physical situation of keeping the radioactive material at some distance from the skin, which effect would be relatively large.

An added consideration is the possibility of high beta doses delivered to personnel from the fallout material lying on the ground and other surfaces. If the highest degree of contamination considered under this policy is safe when in direct contact with the skin, then the beta dose from an equally contaminated ground will not be hazardous. (See criteria III for discussion on unequal contamination on personnel.) However, it is true that the contamination may exceed the amount to deliver dose rates given in graph II and yet not be great enough to consider evacuation. Some personnel may not go indoors, and those who did will eventually be released from this restrictive action and then may walk around in a relatively highly contaminated area. Because of the more limited range of the beta, the location of greatest concern is the lower legs.

One report estimates a beta to gamma dose rate ratio of about 75 to 1 at 10 centimeters above the ground.[11] Under criteria I it was recommended that consideration be given to evacuation when the gamma dose rate reading at 3 feet was, for example, about 6.2 roentgens per hour at H+3 hours. Roughly, this would correspond to about 575 reps per hour of beta at 10 centimeters. Of course, this activity decays, and also it is presumed that personnel would be kept indoors, at least for a few hours. On the other hand, it strongly suggests that biologically significant doses may be delivered to the feet if not protected. Skin lesions were frequent on the bare feet of the natives evacuated during Castle. This probably was a combination of beta dose from material on the ground and from that scuffed up over the bare feet and then clinging to the skin. (No lesions were observed on the bottom of the feet, undoubtedly due to the thick epidermis.) It would be expected that normal closed-type footwear (as compared to open sandals) would afford adequate protection to the feet from such high beta doses as discussed here. There is still no guaranty that beta radiation from material on the ground will not deliver significant biological doses to the ankles and perhaps lower legs, after personnel are released from staying indoors. For example, if the beta dose at 10 centimeters above the ground is 575 reps per hour at H+3 hours, it would be about 250 reps per hour 3 hours later and 160 reps per hour 6 hours later.

One further possibility is the accumulation of radioactive material around the ankles and lower legs resulting from normal walking about the area. This is discussed under criteria III.

Data on human exposures.—The work of Henriques[12] suggests that at the depth of 0.09 mm. in living porcine skin (maximum thickness of epidermis) that "1,400±300 roentgen-equivalent-beta" (delivered over short periods of time so that they may be assumed to be instantaneous) is required to produce recognizable transepidermal injury. The curve of biological damage rises rather

[10] ITR-[illegible]. Study of Response of Human Beings Accidentally Exposed to Significant [illegible] Radiation, Cronkite, E. P., et al. May 1954.
[11] AD-[illegible] (B). An Estimate of the Relative Hazard of Beta and Gamma Radiation from [illegible] Products. Condit, R. I., Dyson, J. P., and Lumb, W. A. S. NRDL 1949. ([illegible]ssified.)
[12] Op. cit.

sharply so that at a dose of just under 2,000 reps (at 0.09 mm.), the epidermis may be expected to exfoliate and in the majority of cases go on to develop chronic radiation dermatitis persisting for months.

The preceding discussion suggests that, using the gamma dose rates listed in these criteria, which are based on an estimated 10 roentgen infinity gamma does, as high as 2,000 reps might be delivered to the basal layer of the epidermis over a period of time covered by the lifetime of the radioactive material.

There have been instances where the calculated infinity gamma dose in areas where personnel were present around the Nevada test site have reached 12 to 15 roentgens, but there have been no known cases of beta burns in these areas. The number of persons involved in these areas of highest contamination was relatively small, perhaps a few dozen, and with an observed duration of fallout of about 1 hour it is possible that they were not in a position to receive the full fallout. Likewise, minute areas of the skin may have been so affected yet not detected or reported. In other areas encompassing some 2,000 people the infinity gamma dose was about 8 roentgens and no instances of beta injury appeared.

The estimated whole-body gamma dose to natives evacuated from the island of Utirik following the March 1, 1954, detonation at the Pacific Proving Ground was about 15 roentgens for a period of about 3 days, but no beta burns appeared. It is fair to assume here that direct contamination took place due to their mode of living, including housing that was quite open to air currents. Gamma dose rate readings were taken over the bodies of the natives at about H+78 hours both on the beach and after boarding the ship. On the beach the personnel readings averaged about 20 mr. per hour gamma (but this probably included some contribution from the ground contamination), and after wading through the surf and boarding the ship the levels averaged 7 mr. per hour gamma.

The 18 natives on Sifo Island, Ailinginae Atoll, received an estimated whole-body gamma dose of 75 roentgens in about 2¼ days. Of these, 14 later experienced slight beta burns, 2, moderate burns, and none showed epilation.

In the case of the Rongelap natives, the estimated whole-body dose was about 170 roentgens in about 2 days. All 64 natives later experienced beta burns to some degree from slight to severe, and over half of the natives showed epilation from slight to severe.

The 16 natives from Rongelap evacuated directly by air to Kwajalein had personnel gamma dose-rate levels generally 80 to 100 mr. per hour although 1 was as high as 240 mr. per hour and 1 as low as 10 mr. per hour (at H+ about 55 hours). The remaining 48 natives evacuated by ship were reported to have personnel readings that "averaged" 60 mr. per hour before decontamination. The picture is further confused because some of the natives had bathed and some had not before the arrival of the evacuation team.

Most of the 28 United States service personnel stationed on Eniwetok Island, Rongerik Atoll, received about 40 to 50 roentgens, based on film badge readings. Three members of the group who were located for part of the time in another section of the island were estimated to have received somewhat higher doses. Seventeen of the twenty-eight personnel showed only slight, superficial lesions with one questionable case of epilation. It should be pointed out that the personnel were in metal buildings during some of the fallout time and for most of the time thereafter until evacuation. This reduced the direct contamination as well as the whole-body gamma dose. A film badge hanging on the center pole of a tent at one end of the island read 98 roentgens. Calculations based on dose-rate readings at another part of the island indicated somewhat lower doses, if personnel had remained in the open for the period of time from fallout (about H+7.5 hours) to evacuation (at about H+34 hours). Upon arrival at Kwajalein 1 personnel gamma dose rate reading was as high as 250 mr. per hour at about H+35 hours.

The above data do suggest that there may be possible a rough bracketing of gamma-beta doses versus beta burns. On the one hand, the natives from Utirik received an estimated whole-body gamma dose of 15 roentgens and showed no evidence of beta burns. On the other hand, the natives on Sifo Island, Ailinginae Atoll, received about an estimated whole-body gamma dose of 75 roentgens, with 14 personnel showing slight burns, 2, moderate burns, 2, no burns, 3 with moderate epilation, and 15 with no epilation. In addition, Rongelap natives received 170 roentgens whole-body gamma dose, and about 90 percent showed some degree of lesions and 56 percent some degree of epilation.

under 2,000 reps (at 0.09 mm.), the epiderm
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It is to be recalled that: (*a*) The natives probably were out of doors and received the full fallout; (*b*) the oily hair, seminaked, perspiring bodies, including bare feet, and lack of bathing for most, would tend to collect and hold the fallout material; (*c*) the time of delivery of essentially all of the doses was 2 to 3 days. Further, it may be speculated that the fallout on the more distant island of Utirik (about 300 statute miles) would consist of smaller particles and also perhaps lesser possibility of overlapping of radiation fields from these particles.

Some of the relevant data are summarized in table II. Due to the uncertainty of the degree of exposure of personnel on Rongerik to the direct fallout, this group is not included. It is to be immediately emphasized that any comparisons made or implied in the table are at the most only semiquantitative. Table II will be referred to in criteria III and IV but is included here as a summary of the data discussed above.

TABLE II

I	II	III	IV	V	VI			
Location	Estimated time of fallout (hours)	Best estimate of whole-body gamma dose (roentgens)	Skin effects	Personnel reading	Best estimate of average dose rates (mr./hr.) of the islands (taken at 3 feet above the ground) and of natives (personnel readings) after removal from radiation field, both at approximately same time			
					Island	Personnel	Ratio	Approximate time
Rongelap	5½	170	Lesions: 6 none. 10 slight. 22 moderate. 17 severe. Epilation: 28 none. 11 slight. 11 moderate. 14 severe.	(a) Majority: 80-100 mr./hr. at H+54 hours.[1] (b) Average: 60 mr./hr. at H+50 hours. Corrected average: 80 mr./hr.[3]	1300	80	16/1	H+50 hours.
Ailinginae	5½	75	Lesions: 2 none. 14 slight (very superficial). Epilation: 15 none. 3 moderate.	Average: 40 mr./hr. at H+52 hours. Corrected average: 53 mr./hr.[3]	410	53	8/1	H+52 hours.
Utirik	16-18	15	Lesions: None. Epilation: None.	Average: 20 mr./hr. Assumed: 15 mr./hr. at H+78.[4]	110	15	7/1	H+78 hours.

[1] 16 natives evacuated by air to Kwajalein and monitored upon arrival.

[2] 48 natives evacuated by U. S. S. *Philip* and monitored aboard the ship. Data suggest meter readings low by about 50 percent since natives from same island read 80 to 100 mr./hr. at Kwajalein some 4 hours later with calibrated meters.

[3] 40 mr./hr. corrected to 60 mr./hr. according to information in footnote 2. Report did not indicate range of values among individuals nor at different parts of body.

[4] Readings taken by monitors from the *Renshaw* on the Utirik beach where there may have been some contribution to dose rates from land. After wading to ship, average personnel readings were 7 mr./hr.

			6 none. 19 slight. 22 moderate. 17 severe. Epilation: 28 none. 11 slight. 11 moderate. 14 severe.	(a) Majority: 80-100 mr./hr. at H+54 hours.[1] (b) Average: 60 mr./hr. at H+50 hours. Corrected average: 80 mr./hr.[3]	1300	80	16/1	H+50 hours.
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Data on animal exposures.—The data on animal exposures are less firm than those for humans. Unmistakable beta burns occurred on cattle at Alamogordo in July 1945, on cattle at the Nevada Proving Grounds in spring 1952, and on horses in spring 1953. (The skin damage observed on sheep in the spring 1953 was not established to be beta burns.) However, the exact positions of the animals in relation to known amounts of fallout are not clear.

Following the last detonation of the spring 1952 series at the Nevada Proving Grounds, about one-half of a herd of 150 head of cattle were found to have evidence of beta burns. They were thought to have been 15 to 20 miles from ground zero in Kawich Valley to the northeast and to have been exposed to fallout from the last detonation. Highest dose rate readings taken along a dirt road running lengthwise through this valley integrated to 75 to 100 infinity gamma doses.

During Upshot-Knothole, 16 horses showed skin lesions over the back, and eye damage was noted in a few. The best evidence indicated that the horses were some 10 to 12 miles to the east of ground zero on March 17, 1954, where the fallout occurred from the first detonation (about 15 KT on a 300-foot tower). Radiation levels in this area are not known with certainty, but the fallout occurred in a narrow band and was carried by relatively high velocity winds so that it probably fell on the horses at a time less than 1 hour. If so, probably more than one-half of the infinity dose was delivered during the next day.

Addendum

Since the original discussion above was written, further consideration has been given to the work of Strandqvist and others [13] on the effect of fractionation of doses delivered to the skin and the onset of the observed results. It will be recalled (p. 10) that X-ray doses to the skin were fractionated in equal daily amounts, and the biological effects compared to a one-treatment dose. A log-log plot of total doses versus days after initial treatment yields straight lines.

Basically, this means that as doses are being delivered to the skin a certain rate of repair is taking place. The overall effect might be that higher initial doses from fallout material might be allowed than if one were to integrate the dose over a period of time without consideration for the repair. Because of the difference in shapes of the total beta dose curves for varying times of initial fallout versus Strandqvist X-ray curves the difference between the two curves cannot be expressed as a simple relationship.

Strandqvist quotes a 1,000 roentgen dose in 1 treatment to produce erythema using X-rays (a somewhat smaller number than other data quoted above), 1,250 roentgens if divided into 2 equal daily doses, 1,450 roentgens if divided into 3 equal daily doses, etc. Of course, there are differences between these X-ray doses and beta doses from fallout material, such as differences in doses at increasing depth of tissue and the fact that the X-rays were delivered essentially as an instantaneous dose at intervals of a day while the beta dose rates are assumed to follow the $t^{-1.2}$. However, accepting the assumptions of biological equivalence of these roentgen and beta doses and $t^{-1.2}$, one may then ask the question, "What will the beta dose rates at varying times after detonation that the contamination occurs such that the integrated doses to the skin will at no time equal Strandqvist curve for erythema?"

For early fallout times the limiting factor will be to keep the first day's beta dose below 1,250 reps; for later times of initial fallout the first day dose may be less than 1,250 reps but subsequent accumulative doses may be greater than Strandqvist curve. A family of curves was prepared of beta dose rates versus time after contamination such that each would meet but not exceed Strandqvist curve for erythema for times out to 40 days, then, based on the discussion contained under Criteria I, a conversion factor of 125 was selected to convert beta dose rates at a depth of 7 mg./cm.^{2} of tissue to gamma dose rates at 3 feet above an infinite plane. These gamma dose rates are plotted in appendix C (a).

If one accepts all the assumptions that go into preparing this curve, then one does not have to estimate the variable of how long the fallout material was in contact with the skin, for the curve suggests that as long as the initial indicated gamma dose rates are not reached, then erythema might not be expected to occur. (However, this approach still does not give assurance that *single* hot particles will not produce erythema.)

Generally, the gamma dose rate readings in the curve (appendix C (a)) suggest theoretical maximum infinite gamma doses of about 20 roentgens for a 1-hour fallout, to about 55 roentgens for a 2-day fallout. For those early times after detonation when relatively heavier fallout might be anticipated, this in-

[13] Sievert, Rolf M. The Tolerance Dose and the Prevention of Injuries Caused by Ionizing Radiations. British Journal of Radiology. Vol. XX, No. 236, August 1947.

finity gamma dose is 2 to 3 times greater than the 10 roentgens which was used as a basis of developing criteria II. However, there are two further considerations: One, the interpretation of the data, and certainly the assumptions made in developing the curve in appendix C (a) are open to discussion. Two, if one accepts the interpretations and assumptions it means a safety factor of 2 to 3—not an unreasonable quantity.

Operational feasibility.—Under the criteria recommended in criteria II, there would have been two occasions in the past where personnel would have been requested to remain indoors. Once was at Lincoln mine following the second detonation of Upshot-Knothole where they were so requested to remain indoors for 2 hours and the other occasion would have been at Riverside Cabins (population about 15) following the ninth detonation of the same series. The dose rate reading at Lincoln mine was 580 mr. per hour at H+2. In the case of Riverside Cabins, however, the radiological conditions were not ascertained until after the fallout had occurred. The maximum infinity gamma dose in the latter case was 12 to 15 roentgens.

Personnel were requested to remain indoors (for about 2 hours) following the ninth detonation of Upshot-Knothole. The highest dose rate reading was 320 mr. per hour at H+4.5 hours. This is less than the current recommendations.

CRITERIA III. DECONTAMINATION OF PERSONNEL

Where it is not possible to monitor personnel outside of a general radiation field, it is recommended that an estimate be made of the degree of personnel contamination by determining the location of the individual at the time of fallout. In the event there is uncertainty as to the validity of such an estimate, the assumption will be made that the individual was out-of-doors. In those areas where the infinity gamma dose equals or exceeds 10 roentgens, it is recommended that the individual be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field where personnel contamination exists over relatively large areas of the exposed body (one-half square foot or more):

When the reading of a survey instrument held with the center of the probe or center of the ionization chamber 4 inches from the center of the contaminated area equals or exceeds the values given in graph III, it is recommended that personnel shall be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field, where personnel contamination exists over relatively small areas of the exposed body (less than one-half a square foot):

The recommended maximum values shall be one-half those given in graph III. Monitoring of the head, arms, hands, lower legs, and feet will be considered as coming under this category. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceeds those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field, and the contamination exists over only spots of exposed body (about the size of a half dollar or less):

The recommended maximum values shall be one-fifth those given in graph III. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field and the contamination exists over any size area on the exterior surface only of the clothing:

The recommended values under these conditions will be twice those given in graph III. The first recommended action shall be to resort to such simple acts as brushing off the clothing. If this action does not reduce the radiation levels to twice those given in graph III or less, then personnel shall be advised to change clothing and to bathe.

When the general contamination of a community of the degree to produce an estimated maximum theoretical infinity gamma dose of 20 roentgens or greater, personnel who have been out-of-doors at any time during the first 2 days and generally moving around in the area (as opposed to such an act as walking only between a building and a vehicle) shall be advised to brush off the footwear (outdoors), to bathe, and to change clothing as soon as possible after the final return indoors each day. In addition, personnel who go out-of-doors for any length of time during the first 2 days after such a fallout shall be advised to wash their hands at least after the final return indoors each day, and more frequently if possible.

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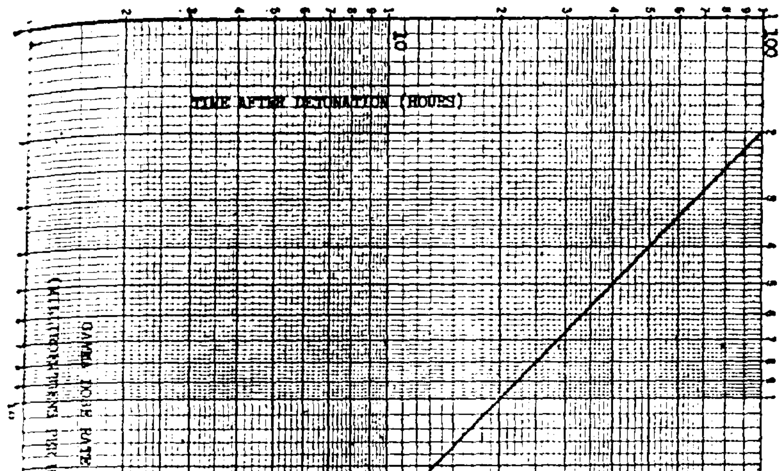

Discussion

Data on humans.—In table II it was suggested that the relative average gamma dose rates from an infinity contaminated field at 3 feet above the ground, compared to that on the natives measured by a survey meter held close to the body was:

$$\frac{110 \text{ mr./hr.}}{15 \text{ mr./hr.}} \cong 7/1 \text{ (Utirik Atoll)}$$

$$\frac{410 \text{ mr./hr.}}{53 \text{ mr./hr.}} \cong 8/1 \text{ (Ailinginae Atoll)}$$

$$\frac{1{,}300 \text{ mr./hr.}}{80 \text{ mr./hr.}} \cong 16/1 \text{ (Rongelap Atoll)}$$

It is recognized that there are many uncertainties in estimating such a relationship by this means. Even if one assumes the dose rate readings were taken accurately, the factors involved, especially in relation to the amount of material collected and retained on the body, certainly are not constant. The higher ratio at Rongelap Atoll might have been due to a physical phenomenon where the quantity of material falling per unit area was so great that it was not retained so completely on the body. Even if this explanation is accepted, there still remain many questions.

Theoretical considerations indicate a gamma dose rate ratio at 3 feet above an infinitely contaminated field to that at 4 inches from an equally contaminated field of 6-inch radius to be about 7/1. (See appendix D.)

The sizes of areas and distances from the surfaces were selected independently of any of the information on the fallout on the natives discussed above and were estimates of areas of contamination and distances of monitoring that appeared to be reasonable estimates of these parameters. The close agreement between the gamma dose rate ratios based on theoretical considerations and those observed with the natives is circumstantial. For example, an equally contaminated area of 3-inch radius would yield a theoretical gamma dose rate nearly 3 times less than the selected area of 6-inch radius. In the case of the natives, however, it is believed that they were seminaked, perspiring, and out-of-doors during the fallout, so that it is not unreasonable to expect relatively large areas of the body to be contaminated. In fact, this was noted when they were monitored. By their acts of walking around during the period of fallout and sleeping on mats that were heavily contaminated it would seem possible that significant areas of the bodies of the Ailinginae and Utirik natives could be as heavily contaminated as was the ground. (It is unknown if there were sufficient winds that might have raised the material from the ground to the body after fallout occurred.)

There is further uncertainty of what is meant by the monitor's report of "average" personnel readings. The dose rate readings in the hair are known to have been significantly higher than the rest of the body in most cases. It is unknown how these readings were "averaged."

Whereas these data certainly are not firm enough for one to place great confidence in the precise quantities of the ratios of 7/1 or 8/1, they do indicate the obvious fallacy of accepting a 10-roentgen infinity dose based on gamma dose rates measured on personnel outside the radiation field. For example, the natives from Ailinginae showed personnel dose rates readings that would approximate 9 roentgens (gamma) in 2¼ days, and yet skin damage to some degree was evident in 14 out of 16 of the personnel. On the other hand, the natives from Utirik showed no skin damage, with an estimated 2.2 roentgens in 2½ days based on gamma dose rates measured on personnel. The uncertainty of these data was discussed under criteria II. They do suggest, however, that if the contamination of a relatively large area of the exposed body produces less than 1 roentgen infinite gamma dose as measured by a survey meter held 4 inches from the surface there is a large probability that beta burns will not result. (See also discussion under criteria II.)

Doses from small sources.—When the same dose rate reading is produced at a given height above a surface from a smaller area, *the amount of contamination* per unit area is greater (other factors being equal). Therefore, it would seem desirable to reduce the recommended dose rate levels when relatively small areas are involved. It is recognized that radiation from another nearby spot may

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contribute to the survey meter reading when monitoring a small area on person-
nel, but this has not been taken into account, first, because of the difficulty of
establishing a prior appraisal of this variable factor and, second, whatever this
contribution may be it will now become an added safety factor.

Of course, the problem is still complex, because when considering smaller and
smaller areas the eventual end point is a single particle. An estimate of beta
doses at the surface of an imaginary sphere surrounding a fallout particle is
given in appendix E and an estimate of beta doses from a single particle required
to produce recognizable erythema is presented in appendix F. Calculations indi-
cate that the specific activity of some individual particles found in fallout would
be great enough to produce recognizable erythema if held in contact with the
skin for less than 1 day, yet the gamma dose rate reading at 4 inches may be
relatively small. (See appendix G.)

Additional information on doses from individual particles has recently been
reported.[34] The particles found in and around Hanford consisted principally of
three radioisotopes, Ru-103, Ru-106, and its daughter Rh-106. The data and
calculations in appendix H also strongly indicate that a single fallout particle
could produce a recognizable erythema.

Contamination of clothing.—In the case of contamination of clothing, higher
dose rates might be tolerated than those for exposed parts of the body. This
was exemplified in the natives where no beta burns were observed under clothing
of the most highly contaminated personnel. (This does not include such areas as
under the waist line where material apparently collected and was held in place.)
On the other hand, very large increases in contamination should not be tolerated
since it is possible for the clothing to be rearranged so as to bring the contam-
inated surface in contact with the skin. Further, it is not unlikely that one
may rub his hands over his clothing and then through the hair where the mate-
rial could be held in place for relatively long periods of time.

Beta exposure to the hands.—A further consideration is the beta dose to the
hands resulting from handling objects contaminated with fallout material. Al-
though some data are available on beta burns from handling radioactive objects,
the conditions are so different from those associated with fallout that compari-
sons probably would not be valid.[35]

If the above assumptions and calculations are correct concerning contamina-
tion of a general area from fallout, then the transfer of all the radioactive mate-
rial to the hands from an object of equal area would not constitute a hazard.
Thus, one might consider using as criteria for monitoring objects, the dose read-
ings given above for monitoring personnel outside the general radiation field.
However, the problem is more complex, since the hands may come into contact
with contaminated surfaces many times larger in area than the hands, with an
undetermined percentage of activity being transferred to the hands. Of course,
an added uncertainty is the frequency of washing of the hands and/or the rub-
bing off of the material from the hands.

Further, one might speculate that a given surface could have significantly
higher contamination than the general area and that the handling of such a sur-
face could constitute a greater risk. This might be true because of the greater
amount of activity transferred to the hands or because of the doses delivered
during the time of actually handling the object. The uncertainty of the percent-
age of transfer of material has been mentioned. One uncertainty in the second
case is the length of time the object would be handled.

Based on calculations in appendixes B and D, when an object is held in a hand,
a rough estimate of the ratio of dose rates of beta to the basal layer of the epider-
mis to that of the gamma reading on a survey meter held 4 inches away from an
object 2 inches in radious (outside a general radiation field) might be 5,000 to
1 (appendix I). Thus, if this object were contaminated with the same activity
per unit area that would produce an infinity 10-roentgen whole-body gamma dose
from general contamination of the area, it would produce about 50 mr. per hour
gamma at 4 inches away at H+1 hours, and about 250 reps per hour at a depth
of 7 mg./cm.². Since the palms of the hands have an approximate epidermal
layer of about 40 mg./cm.² the beta dose to the basal layer would be about 170

[34] HW-... , A ... report, September 17, 1954.
[35] Beta Ray Burns of Hands Skin, Knowles et al., The Journal of the American Medical Association, v. 141, No. 4, September 24, 1949.

reps per hour. (The time of H+1 was selected to show about the highe nitude of dose rates.) If one assumes that the decay is according to t^{-} the total beta dose to the basal layer of the epidermis of the hand in th 10 hours would be about 320 reps.

Whereas the above estimates do not indicate an alarming situation, a serious problem may come when the contamination is just less than that evacuation is indicated. For example, the contamination of the genera may be 5 or 6 times that used as an illustration in the preceding parag without evacuation being recommended. Thus, beta dose rates from ha objects, especially in times soon after fallout, may be high enough to be a pro A simple and expedient procedure to reduce this factor is frequent washi the hands after handling objects that were in the fallout.

Beta exposure to the feet and lower legs.—It was suggested in criteria II normal closed-type footwear (as compared to such as open sandals) would ably afford adequate protection against significant beta doses to the feet fallout material on the ground. There is still the added problem if the mat be scuffed up and cling to the ankles and lower legs. If there were no inter ing clothing, or perhaps even with thin stockings or socks, this might resu significant biological beta doses being delivered to these parts. For exampl the gamma dose rate reading at H+3 hours were something less than 5 roent per hour, evacuation would not be indicated. However, for fallout materia the same concentration in contact with the skin the beta dose rate at 7 mg./ would be about 600 reps per hour. (See appendix B.) Presumably, person would be kept indoors for a few hours, but upon release the approximate beta rates at 7 mg./cm.^{2} would be 260 reps per hour 3 hours later, or 210 reps hour 6 hours later. In addition, there is the variable factor of what concentra of fallout material may accumulate in the ankle region by walking around an ar

A concentration of fallout material on the ground that would result in ab 20 roentgens maximum theoretical infinity gamma dose if in contact with skin, would result in a beta dose rate to the basal layer of the skin of abou those indicated in the previous paragraph.

CRITERIA IV. MONITORING AND DECONTAMINATION OF MOTOR VEHICLES

It is recommended that when the predicted fallout across a main highw will be equivalent to a 10-roentgen infinity gamma dose or higher, vehicles held until after the actual fallout has essentially ceased. They should be the warned to proceed with windows and air vents closed, and the cars should be monitored after passing through the contaminated area. When 5 to 10 roent gens are predicted across a main highway, vehicles should be warned to proceed with windows and air vents closed and should be monitored after passing through the contaminated area. Monitoring and warnings should be continued until there is reasonable belief that no or very few additional vehicles will exceed the values given in graph IV.

When the dose rate reading taken inside a vehicle, or taken over any exterior area that is readily accessible, equals or exceeds the values given in graph IV, the vehicle shall be cleaned inside and outside. Exterior areas to be monitored should include the wheels and under parts of the fenders but not the under car riage. The survey meter should be held approximately 4 inches from any surface.

…ime of H+1 was selected to show about the highest mag-… If one assumes that the decay is according to $t^{-1.2}$, then … the basal layer of the epidermis of the hand in the next … 320 reps.

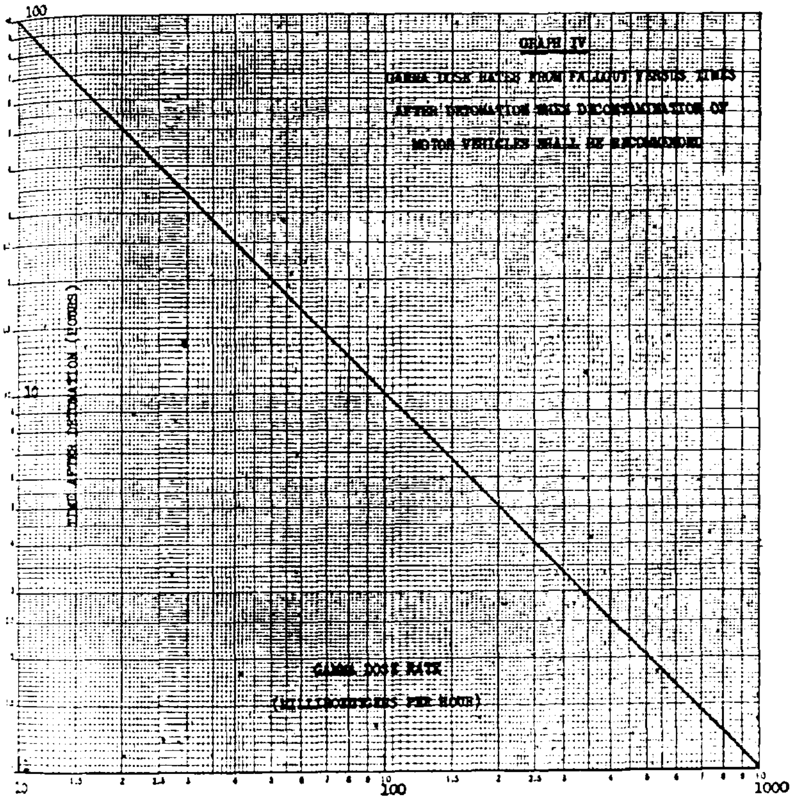
…estimates do not indicate an alarming situation, a more …ome when the contamination is just less than that where …l. For example, the contamination of the general area …hat used as an illustration in the preceding paragraph, …ng recommended. Thus, beta dose rates from handling …es soon after fallout, may be high enough to be a problem. …t procedure to reduce this factor is frequent washing of … objects that were in the fallout.

…*fe… t and lower legs.*—It was suggested in criteria II that …wear (as compared to such as open sandals) would prob-…otection against significant beta doses to the feet from …ground. There is still the added problem if the material …to the ankles and lower legs. If there were no interven-… even with thin stockings or socks, this might result in …ta doses being delivered to these parts. For example, if …ding at H+3 hours were something less than 5 roentgens …ould not be indicated. However, for fallout material of …in contact with the skin the beta dose rate at 7 mg./cm.[2] …s per hour. (See appendix B.) Presumably, personnel …r a few hours, but upon release the approximate beta dose …ld be 260 reps per hour 3 hours later, or 210 reps per …ddition, there is the variable factor of what concentration …ccumulate in the ankle region by walking around an area. …llout material on the ground that would result in about …theoretical infinity gamma dose if in contact with the …eta dose rate to the basal layer of the skin of about 1/4 …vious paragraph.

…TORING AND DECONTAMINATION OF MOTOR VEHICLES

…at when the predicted fallout across a main highway …10-roentgen infinity gamma dose or higher, vehicles be …al fallout has essentially ceased. They should be then …windows and air vents closed, and the cars should be …through the contaminated area. When 5 to 10 roent-… a main highway, vehicles should be warned to proceed …its closed and should be monitored after passing through … Monitoring and warnings should be continued until …that no or very few additional vehicles will exceed the …

…ding taken inside a vehicle, or taken over any exterior …ssible, equals or exceeds the values given in graph IV, …ed inside and outside. Exterior areas to be monitored … and under parts of the fenders but not the under car-…should be held approximately 4 inches from any surface.



…cussion

…n the past, fallout has occurred across highways in significant quantities. …ble IV-b below indicates some pertinent data during Upshot-Knothole.

TABLE IV-B

…t No. (…no-…gical)	Approx-imate yield (KT)	Tower (feet)	Time of fallout (hours)	Estimated dose rate reading of highway at time of fallout (mr./hr.)	Location	Approx-imate distance from ground zero (miles)
-------	------------	300	1¼	920	30 miles south of Alamo on Highway No. 93.	60
-------	------------	300	2¾	260	1 mile north of St. George, Utah.	130
-------	------------	300	5	325	Junction of U. S. Highway No. 91 and Nevada Highway No. 40.	80
-------	------------	300	4½	760	20 miles northwest Glendale, Nev., on Highway No. 93.	65
-------	------------	300	7	400	8 miles west of Mesquite, Nev., Highway No. 91.	105
-------	------------	300	2	1,000	30 miles north Glendale on Highway No. 93.	60
-------	------------	300	3¼	420	St. George, Utah, Highway No. 91.	130

Road blocks were established on Highways 93 and 91 following shots Nos. 7 and 9 of Upshot-Knothole. The highest reading on a private automobile was 100 mr./hr. (gamma) inside and 110 mr./hr. outside at H+3½ hours. About [illegible] cars were washed (roughly one-eighth of the total monitored). All of the cars that were washed, except the *one* mentioned above, had outside dose rate readings less than half of the highest. The ratio of dose rate readings on the outside of the car to inside varied from unity to about 4/1. Probably one of the important factors here is the difference between driving with windows and/or ventilators opened or closed.

One bus read 250 mr. per hour outside and average of 100 mr. per hour inside with a high inside reading over the rear seat of 140 mr. per hour at H+8¾ hours.

Considering the amount of time one normally spends in an automobile, these dose rates do not necessarily represent a health hazard in terms of gamma doses. What is *probably* a more limiting factor is the direct contamination one might acquire by rubbing against the outside of the car, especially when changing a tire.

It is assumed that monitoring will be accomplished outside a general radiation field. Theoretical calculations (appendix D) indicate that gamma dose rate readings taken at 4 inches from a surface will be 51 percent, 42 percent, and 27 percent of those by a meter at 3 feet above an equally contaminated infinite field when the radii of contamination are respectively 3 feet, 2 feet, and 1 foot.

These data suggest that when the gamma dose rate reading at 4 inches from a generally contaminated car is about one-half that for an infinite plane taken at 3 feet, the degree of contamination per unit area will be about equal; and when the wheels are being monitored ½ to ¼ of a gamma dose rate reading will represent equivalent contamination (depending on the gamma contribution from the body of the contaminated vehicle).

Another factor to be considered is that the probability of collecting fallout material on the body from a generally contaminated area in which one lives is greater than from one's automobile. On the other hand, it has been noted in the past that significantly higher amounts of contamination have been found on the tires and under parts of fenders than on the remainder of the car. (Undoubtedly, this is a simple phenomenon of picking up the activity from the highway.) If one were to change a heavily contaminated tire, significant amounts of radioactive material might accumulate on the hands, and later be transferred to the hair or eyes by a simple rubbing of the hands over those parts.

A comparison might be made here between recommended maximum dose rates found on personnel and the establishing of levels of activity for automobiles. There is one obvious difference, howewver: in the first case the material is already on the person while in the second case one has to introduce the factor of probability of transfer of contamination (and to what degree) from the car to the body.

The dose rates (measured as stated) in graph IV would represent about equal contamination per unit area for a car as for an infinite plane if the car were rather uniformly contaminated. If the activity were confined, say, principally to the tires and under parts of the fenders, the dose rate readings might represent nearly twice the degree of contamination. One must weigh this condition with the probability that a tire will be changed before he activity has decreased significantly.

A given dose rate reading inside a vehicle may represent less contamination per unit area due to the contribution of gamma radiation from the exterior of the vehicle. On the other hand, contamination within a vehicle would more probably be picked up by personnel than if it were on the outside. Further, it is recognized that significantly high concentrations of radioactive fallout may accumulate in such parts as the air filters of an automobile. Again, this has to be weighted against the probability that they will be handled before the activity has decreased to low levels plus the fact that it is relatively difficult to monitor such parts on a mass basis. The uncertainties present in estimating possible hazards from vehicle contamination would not justify fine distinctions in monitoring the various parts. A thorough cleaning, inside and outside, would appear to be the best solution.

One of the obvious ways to avoid much of the problem discussed in criterion IV is to prevent vehicles entering an area during the time of fallout. This will not prevent the first vehicles passing through from picking up activity on the tires from the highway. It is believed, however, this will not constitute such a troublesome problem, and past experience has indicated that the activity found lished on Highways 93 and 91 following shots Nos. 7 e. The highest reading on a private automobile was de and 110 mr./hr. outside at H+3½ hours. About 75 ly one-eighth of the total monitored). All of the cars the one mentioned above, had outside dose rate read- highest. The ratio of dose rate readings on the out- varied from unity to about 4/1. Probably one of the the difference between driving with windows and/or sed.

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r inside a vehicle may represent less contamination ontribution of gamma radiation from the exterior r hand, contamination within a vehicle would more rsonnel than if it were on the outside. Further, it is high concentrations of radioactive fallout may ac- the air filters of an automobile. Again, this has to bability that they will be handled before the activity lus the fact that it is relatively difficult to monitor . The uncertainties present in estimating possible nination would not justify fine distinctions in moni- thorough cleaning, inside and outside, would appear

o avoid much of the problem discussed in criterion ering an area during the time of fallout. This will s passing through from picking up activity on the is believed, however, this will not constitute such a st experience has indicated that the activity found

the tires noticeably decreased after several cars had passed over the highway. Further, if vehicles are not present in the fallout it will help reduce contamination of the passengers and of the insides of the vehicles.

Operational feasibility.—In the past, the criteria used for washing cars has been 7 mr./per hour, and at a later time 20 mr./per hour (gamma), inside a vehicle. This resulted in washing about 75 cars (roughly one-eighth of the total monitored) following the seventh and ninth detonations of Upshot-Knothole. Under the recommendations given in criteria IV, the bus mentioned above, but probably none of the cars, would have been washed.

The data given in graph IV-b indicate that if these radiation levels given had been predicted before the fallout. Highways Nos. 91 and 93 would have been closed prior to the fallout from the seventh detonation and possibly Highway No. 93 for the ninth detonation.

CRITERIA V. CONTAMINATION OF WATER, AIR, AND FOODSTUFFS

In any area where the theoretical gamma infinity dose exceeds 10 roentgens, adequate sampling of the water, air, and foodstuffs should be made to ascertain the conditions of possible contamination. Based on past data, however, it is not expected that under those conditions of fallout, where the radiation levels are below those stipulated for possible evacuation, that the degree of contamination will be a health hazard. (Nor is it implied here that any level above this does constitute a serious contamination of water, air, or foodstuffs.) Therefore, it is recommended that no action be taken in regard to limiting intake except to advise the washing off of such exposed foods as leafy vegetables when that action seems desirable.

Discussion

Water.—Table VI-A lists the six locations having the highest concentrations of fission products in water sources during Upshot-Knothole, and for comparative purposes the estimated external theoretical maximum gamma infinity doses.

TABLE VI-A

Locality	Concentration (microcuries per milliliter extrapolated to 3 days after detonation)	External theoretical maximum wholebody gamma infinity dose (roentgens)
...in River irrigation canal, Nevada	8.7×10^{-5}	6.0
...ation ditch, 56 miles north of Pioche, Nev.	4.5×10^{-5}	.15
...er Pahranagat Lake, Nev.	3.2×10^{-6}	2.0
...in River at Mesquite, Nev.	2.6×10^{-6}	2.5
...nterville, Nev. (tap water)	1.2×10^{-6}	7.0
...ystal Springs, Nev. (tap water)	1.1×10^{-6}	.15

Due to weather and to attenuation of the gamma rays by buildings, the whole-body gamma dose estimated to have been actually delivered was probably closer to one-half of the values shown.

The maximum permissible concentration of fission products in drinking water is $5 \times 10^{-3} \mu c$/ml. extrapolated to 3 days after detonation. This is considered a safe concentration for continuous consumption.

Whereas, the monitoring of water sources is of value for documentary purposes it should be recognized that the concentrations found may vary widely within small geographical areas and even at the same location at different times (taking into account radioactive decay). Thus, confidence cannot be placed in precise values. Table VI-A suggests that even if one were to have stored up the water used at Virgin River Irrigation Canal and subsisted entirely on this for a lifetime, the concentration would be about 58 times less than the maximum permissible amount. Normal factors of dilution by additional rainfall and/or by the influx of lesser contaminated ground water would be expected to reduce the level of activity.

Air.—Considerable effort has and is being made to evaluate hazards from airborne radioactive materials, including fission products. There are certainly many unanswered problems including the possible hazard from a single particle in the lungs. Despite the uncertainties and as yet incomplete analysis of the inhalation hazard, the preponderance of evidence today is that the external gamma hazard from fallout is the more limiting factory of the two.[16] (However, see discussion on food contamination.)

During Upshot-Knothole quite complete data were collected of concentration of airborne activity on about 150 occasions in some 40 different localities within 200 miles of the Nevada Proving Grounds. These included monitoring of all detonations. Histograms were made of air concentrations versus time after detonation for 30 occasions and estimates were made of doses to the lungs. These data for the five communities showing the highest air concentration are given in Table VI–B. The histogram for St. George (the highest 24-hour average concentration of fallout ever measured in a populated area) is reproduced in appendix J.

TABLE VI–B

Locality	24-hour average concentration (microcuries per cubic meter)	Dose to lungs (13 weeks) based on 20 percent deposition and 100 percent retention thereafter (mreps)[1]	Theoretical maximum whole-body gamma 13-week dose (roentgens)
St. George, Utah	1.29	130	[illegible]
Lincoln Mine, Nev	4.0×10^{-1}	12	[illegible]
Mesquite, Nev	1.7×10^{-1}	13	1.0
Groom Mine, Nev	3.4×10^{-2}	7	[illegible]
Pioche, Nev	2.0×10^{-2}	8	[illegible]

[1] The method used in estimating doses to the lungs is given in appendix K.

The criteria previously established by an Ad Hoc Jangle Feasibility Committee (Washington, D. C., July 13, 1951), for air concentrations were—

"At a point of human habitation, the activity of radioactive particles in the atmosphere, averaged over a period of 24 hours, shall be limited to 100 microcuries per cubic meter of air (corresponding approximately to a ground level gamma intensity of 30 mr. per hour).

"The 24-hour average radioactivity per cubic meter of air, due to suspended particles having diameters in the range 0 micron to 5.0 microns, shall not exceed one-hundredth of the above; nor is it desirable that any individual particle in this size range have an activity greater than 10^{-3} microcuries calculated 4 hours after the blast."

In the January 20, 1954, meeting of the ad hoc committee the basis for recommending the above air concentrations was discussed. Essentially, these criteria was selected by estimating the gamma dose that might be delivered by the passing of a radioactive cloud. Since there are better methods of estimating gamma doses and since there are uncertainties in evaluating the hazards of such transitory air concentrations as experienced from fallout, and since the preponderance of evidence from past nuclear test series indicates that the external gamma hazard is more limiting than the inhalation one, it was recommended in the January 20, 1954, meeting to strike from the record the past recommendations for maximum permissible air concentrations. It was recommended that an air monitoring program be continued for documentary purposes and for whatever value the data might have in the future when new analyses might be made in the light of additional knowledge.

A further discussion of the single particle problem may be made. In arriving at the recommendation" * * * nor is it desirable that any individual particle in this size range have activity greater than 10^{-3} microcuries calculated 4 hours after the blast" a computation was made that the average radiation dose from such a particle to a sphere one-half a millimeter in radius would be 385 reps."[17] However, the conclusions may be misleading. In the case of a single particle, relatively large doses are delivered near the particle and small doses at a greater distance. Appendix L suggests one possible estimate of this phenomenon. The

[16] Ad hoc committee meeting, Washington, D. C. Jan. 20, 1954.
[17] Minutes, Meeting of Committee to Consider the Feasibility and Conditions For A Preliminary Radiologic Safety Shot for Jangle. LASL. May 21–22, 1951.

uncertainties and as yet incomplete analysis of [illegible] onderance of evidence today is that the external [illegible] be more limiting factory of the two.[16] (However [illegible] nination.)

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TABLE VI-B

	24-hour average concentration (microcuries per cubic meter)	Dose to lungs (13 weeks) based on 20 percent deposition and 100 percent retention thereafter (mreps)[1]	Theoretical maximum whole-body gamma 12-week dose (roentgens)
	1.29	130	[illegible]
	4.0×10^{-1}	12	[illegible]
	1.7×10^{-1}	13	[illegible]
	3.4×10^{-2}	7	[illegible]
	2.0×10^{-2}	8	[illegible]

[1] doses to the lungs is given in appendix K.

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Washington, D. C. Jan. 20, 1951.
tee to Consider the Feasibility and Conditions For A ot for Jangle. LASL. May 21–22, 1951.

meters involved here are many and difficult to evaluate. For example, how will a particle remain in one place in the lung and what dose will be delivered g that time?

has been suggested that in the upper respiratory passage 20-micron diameter cles are the upper limit of size for deposition and that "Cilia sweep 4 to 6 s per second. The probability of a particle remaining within 1 millimeter for as much as one-half hour appears to be vanishing small. * * * Protec- will also be provided by the mucus lining which is itself renewed several an hour." Accepting the estimates above and the methods illustrated in dixes E and F, it may be computed that about 8 reps would be delivered e surface of an imaginary stationary sphere 1 millimeter in radius by a 20- n particle (0.5 microcurie) in 30 minutes (appendix L). Larger doses be delivered closer to the particle but with the relatively rapid movement he particle, it does not appear that large doses will be delivered to a great er of cells. Multiple exposures might occur from additional particles but this risk is difficult to evaluate.

ood.—Considerable effort is being directed toward the study of contamina- of food from fallout. One element of major concern is Sr-90. It has been ated that if one were to subsist entirely on food grown from soils contain- about one-tenth to 1 microcurie per square foot of Sr 90 (1,000 pounds of m per acre to an average depth of 6 to 7 inches), that over a period of s there would accumulate in the human skeleton a body burden of 1 micro- of Sr-90.[18] The highest Sr 90 activity found in soils from agricultural s about 100 miles from the Nevada test site, now shows a concentration of 3.4×10^{-3} microcuries per square foot. This is a factor of 30–300 times than the one-tenth to 1 microcurie of Sr-90 quoted above. The calcium con- of soils around the Nevada test site is several times greater than the 1,000 ds per acre used as a basis for calculations, which would materially reduce strontium uptake.

Although not of direct concern to the Nevada test site, it is of interest to that soils were collected from the Marshall Islands following the fallout ly March 1954. Appendix M summarizes these data.)

A recent report strongly suggests that contamination of leaf surfaces followed ther direct consumption or intake by way of milk is a far more important way of intake than the soil-plant-animal cycle, at least for those times of when plants may be in a state of growth to collect the fallout. Further ysis is being planned.

is same report raises a new problem. Based on stated assumptions, the presented indicate relative doses of:

thyroid: tens of thousands of reps
Sr^{89-90}: 300 reps
external gamma: 40 roentgens

radioiodine doses to the fetus and baby may be particularly important. tional evaluation will be given this problem.

CRITERIA VI. ROUTINE RADIATION EXPOSURES

The whole-body gamma effective biological dose for off-site populations should exceed 3.9 roentgens over a period of 1 year. This total dose may result n a single exposure or series of exposures.

If integrations of dose rate readings are used in estimating the effective bio- gical doses, then table V may be used.

TABLE V

	Multiplication factor	Effective biological dose
theoretical radiation dose from time of fallout to 15 days [illegible]	¾	
theoretical radiation dose from 15th day to 1 year	½	
best estimate of effective biological dose		

[18] Private communication, L. A. Dean, U. S. Department of Agriculture, Beltsville, Md., [illegible] 25, 1954.

If film badges or dose meters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurate account of the radiation dose received, then the values recorded on the film badges may be accepted with a correction factor of ¾ to account for the difference between the dose received by the film badges or dosimeters (including backscatter) and that received at the tissue depth of 5 centimeters.

CRITERIA VI. ROUTINE RADIATION EXPOSURES

Discussion

In 1953 the following recommendation was made in the report of Committee To Study Nevada Proving Ground:

"It is recommended, and found to be in conformity with the present principles of determining permissible exposure limits, that for test operation personnel the total body gamma exposure be limited to 3.9 r. in 13 weeks, and that the same figure be applied to the off-site communities with the further qualification in the latter case that this is the total figure for the year. In general, this implies a single test series in any given year."

On the basis of this recommendation and the reasoning discussed under criteria I, the criteria for estimating the whole-body gamma effective biological dose are summarized in table V. It will be noted that the biological factor included under criteria I is omitted in criteria V. In the first case we are dealing with relatively high doses that may require emergency measures with their attendant hazards. It is a situation where one wishes to estimate all pertinent factors in evaluating radiation doses even though they may not be known with preciseness, before recommending an emergency action that may produce greater problems. In the case of criteria V one is concerned with relatively lower doses during routine operations. It would be difficult to justify on the one hand the proposition that weekly doses for general populations may be integrated and taken in a single exposure without penalty and on the other hand, that a given dose received over a period of a year may be administratively reduced because of biological repair. Therefore, the biological factor is omitted.

The general effects of backscattering on measured radiation doses are fairly well established. Further, knowledge of depth (tissue)-dose curves has advanced to a quantitative state.[19] Thus, there seems to be little doubt that a film badge or dosimeter worn on the person will overestimate the gamma radiation dose delivered at a depth of 5 centimeters (assumed depth of blood-forming organs). A major factor in determining this difference is the quality of radiation under consideration. One report dealing explicitly with radiation in a fallout field suggests a factor of about ¾.

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[19] Permissible Dose From External Sources of Ionizing Radiation. National Bureau of Standards Handbook 59. September 24, 1954.

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epth of 5 centimeters.

. VI. ROUTINE RADIATION EXPOSURES

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APPENDIX A. SAMPLE ESTIMATION OF GAMMA DOSES SAVED BY REMAINING INDOORS

EXAMPLE I

Assume: Time of fallout = H + 3 hrs
Dose rate at H + 3 = 667 mr/hr

Then: Theoretical maximum dose from time of fallout to 3 hours later	1.30 r
Savings by remaining indoors for 3 hours	0.65 r
1 year effective biological dose if personnel did not remain indoors during the 3 hours (based on same assumptions contained in section on evacuation)	~5.5 r
Percent of 1 year effective biological dose saved by remaining indoors for the 3 hours	~12

EXAMPLE II

Assume: Time of fallout = H + 3 hrs
Dose rate at H + 3 = 667 mr/hr

Then: Theoretical maximum dose from time of fallout to 8 hours later	2.30 r
Savings by remaining indoors for 8 hours	1.15 r
1 year effective biological dose if personnel did not remain indoors during the 8 hours (based on same assumptions contained in section on evacuation)	~5.5 r
Percent of 1 year effective biological dose saved by remaining indoors for the 8 hours	~21

APPENDIX B. *Calculations of Beta Dose Rate at Depth of 7 Milligrams per Square Centimeter From a Thin Extended Source*

Assume: 1.5 Mev Beta (mean energy = 0.5 Mev)
$\mu = 10\ \text{cm}^2/\text{gm}$

(This assumes a single mass absorption coefficient.)

$$N = No\ e^{-\mu x}$$

where

No = number of betas at surface per cm² per sec.
N = number of betas at depth x
μ = mass absorption coefficient
x = distance (depth) under consideration

$$\frac{dN}{dx} = -\mu No\ e^{-\mu x}$$

$$R = \frac{\mu No\ e^{-\mu x} E}{2}$$

where

R = dose rate at depth x
E = mean energy of betas

$$R = \frac{(10)\,No\ e^{-(10)(0.007)}(0.5)}{2} = 2.33\ No\ \text{Mev gm-sec.}$$

$No = 3.7 \times 10^4 C$ where: C = activity in microcuries per cm²
$R = 8.65 \times 10^4 C$ Mev/gm-sec.
$R = (1.39 \times 10^{-1})(C)$ ergs/gm-sec.
$\cong 5.4\ C$ reps/hr
$\cong 5.0\ C$ rads/hr

Example

Assume: $C = 80\mu c/\text{cm}^2$ (beta)
$R = 5.4\ C$

where: R = dose rate at depth 7 mg/cm² in reps
C = activity/cm² in μc

$= (5.4)(80)$
$= 432$ reps/hr
$\cong 400$ rads/hr

Comparison Beta Dose Rate (Reps/hr) at 7 Mg/cm² to Gamma Dose Rate Measured in Infinite Field at 3 Feet Above the Surface

Assume: 80 $\mu c/cm^2$ (beta), equivalent to 1 megacurie/mi² (gamma)

$$\frac{432}{4.1} \cong 105$$

APPENDIX C. *Experimental Data Versus Theoretical Calculations (Appendix B) in Estimating Beta Doses*

In one relevant experiment, a thin P^{32} source was prepared by soaking a filter paper in a solution of phosphates and allowing it to dry. The surface dose rates were then measured with a surface ionization chamber.[1] Pertinent data are abstracted as follows:

Thickness of source	9.6 mg/cm²
Activity of source	77.0 $\mu c/cm^2$
Surface dose rate	0.127 rep/sec; 457 reps/hr
Dosage rate at depth of x centimeters	$e^{-9.5x}$

A. Theoretically:

Using the equation from Appendix B

$$R = \frac{\mu N o e^{-\mu x} E}{2} \text{ (for } P^{32}\text{)}$$

Substituting above data:

$$R = \frac{9.5 N o e^{-(9.5)(0.007)} .69}{2}$$

$= 7.0\ C$ reps/hr

Let $C = 77\ \mu c/cm^2$

Then $R = 7.0 \times 77$

$= 539$ reps/hr at 7 mg/cm² (P^{32})

B. Experimentally:

$R = 457\ e^{-(9.5)(0.007)}$

$= 427$ reps/hr at 7 mg/cm² (P^{32})

The two above approaches are within 26 percent of each other. If one extrapolates the experimental data from a source of 9.6 mg/cm² to a thin source (for comparative purposes) the two methods are within 20 percent.

[1] *Effects of External Beta Radiation.* Zirkle, Raymond E. McGraw-Hill Book Co. 1951.

...ta Dose Rate (Reps/hr) at 7 Mg/cm² to Gamma Dose Rate Measured in Infinite Field at 3 Feet Above the Surface

...cm² (beta), equivalent to 1 megacurie/mi² (gamma)

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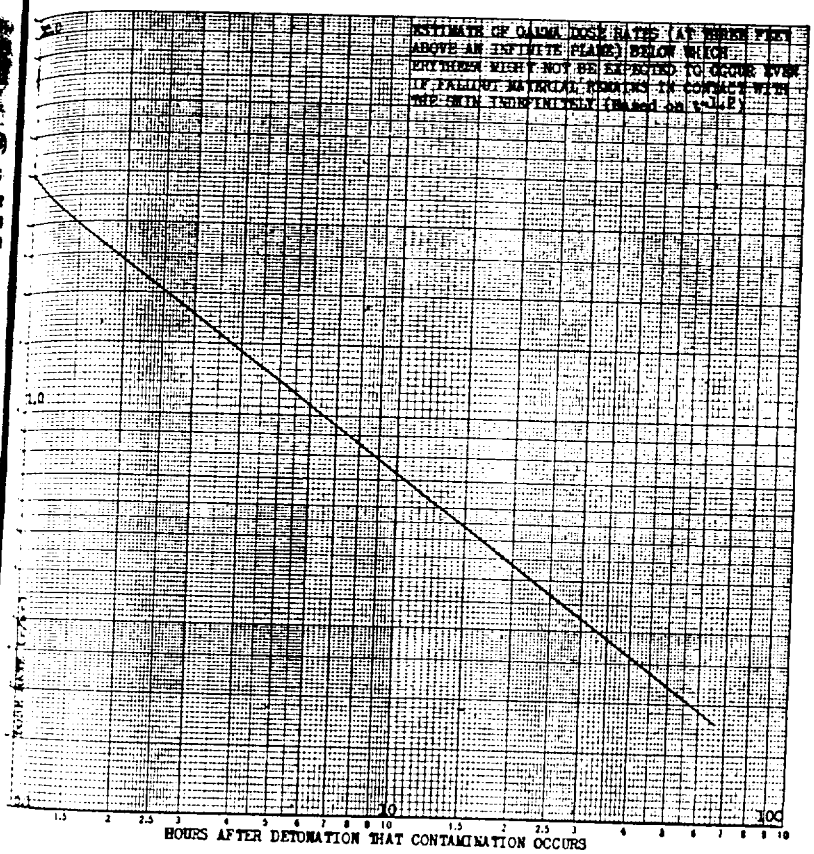
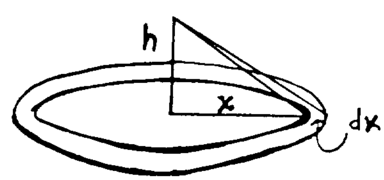
APPENDIX C (a)



...ENDIX D. *Calculations Gamma Dose Rate From a Field 6 Inches in Radius and Center of Chamber 4 Inches Above Surface*

...e rate of gamma from a point source:



$r \cong 6CE$ where: r = r/hr

C = activity in curies per square foot

E = average energy of gammas (Mev)

$$D = 6CE\ 2\pi \int_0^x \frac{x\,dx}{h^2 + x^2}, \text{ where } D = \text{dose rate in r/hr}$$

$$D = 18.8\ CE \ln\left[\frac{h^2 + x^2}{h^2}\right]$$

Example:

Let: $x = 1/2$ foot
$C = 40 \mu c/cm^2$ or 3.6×10^{-2} c/ft² (gamma)
$E = 0.7$ Mev
$h = 1/3$ foot

$$D = (18.8)(3.6 \times 10^{-2})(0.7) \ln \left[\frac{(1/3)^2 + (1/2)^2}{(1/3)^2} \right]$$
$$= 0.56 \text{ r/hr}$$

Comparison Gamma Dose Rates From Infinite Plane at a Height of 3 Feet Ground to Area of 6-Inch Radius and Height of 4 Inches

Assume: 1 megacurie/mile²
(3.6×10^{-2} c/ft²)

$$\frac{4.1 \text{ r/hr}}{0.56 \text{ r/hr}} = 7.3$$

APPENDIX E. *Estimate of Dose Delivered by a Single Particle of Fallout*

Assume: a. Point source
b. 0.5 Mev average beta energy
c. $\mu = 10$ cm²/gm
d. Rate of decay follows $t^{-1.2}$

The dose delivered at the surface of an imaginary sphere at distance R point source.[1]

(1) $$K(R) = \frac{CE\mu \, e^{-\mu R}}{4\pi R^2} \frac{\text{Mev}}{\text{gram}}$$

where: $K(R)$ = dose delivered at the surface of an imaginary sphere at dist
E = average energy of beta particles
C = total number of disintegrations
μ = mass absorption coefficient

Substituting:

$$\mu = 10 \text{ cm}^2/\text{gm}$$
$$E = 0.5 \text{ Mev}$$

Then: (2) $$K(R) = 0.4 \frac{e^{-10R}}{R^2} \frac{\text{Mev}}{\text{gm-disintegration}}$$

or (3.a.) $$K(R) = 6.9 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{milli reps}}{\text{disintegration}}$$

or (3.b.) $$K(R) = 6.4 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{millirads}}{\text{disintegration}}$$

NOTE.—Equation (3.a.) is plotted on the attached graph.

For fission products:

(4) $$A_a = A_1 t_a^{-1.2}$$

where: A_a = disintegrations per unit time at time "a" after detonation
A_1 = disintegrations per unit time at one unit of time after detonation

Integrating equation (2),

(5.a.) $$C = 5A_1(t_a^{-0.2} - t_b^{-0.2})$$
and (5.b.) $$C = 5A_a t_a^{1.2}(t_a^{-0.2} - t_b^{-0.2})$$

where: C = total number of disintegrations from time "a" to "b"
t_a = time after detonation
t_b = later time after detonation.

When t_b is infinite,

(6) $$C_\infty = 5A_1 t_a.$$

By the use of equations (3.a.) or (3.b.) and (5.b.) one may compute an estimated dose at the surface of an imaginary sphere.

Of course, the problem is the determination of "t_a" and "t_b", i. e., how long after detonation will a radioactive particle be deposited and how long will the particle remain in place. The first time (t_a) is much easier to estimate than the later (t_b).

[1] Ross, [illegible] and Ellis, R. H. "Distributed Beta Sources in Uniformly Absorbing Media.". *Nucleonics* July 1950, V. 7 No. 1.

et: $x = 1/2$ foot
$C = 40 \mu c/cm^2$ or 3.6×10^{-2} c/ft² (gamma)
$E = 0.7$ Mev
$h = 1/3$ foot

$$D = (18.8)(3.6 \times 10^{-2})(0.7) \ln \left[\frac{(1/3)^2 + (1/2)^2}{(1/3)^2} \right]$$
$$= 0.56 \text{ r/hr}$$

nma Dose Rates From Infinite Plane at a Height of 3 Feet Above ***
ound to Area of 6-Inch Radius and Height of 4 Inches

Assume: 1 megacurie/mile²
(3.6×10^{-2} c/ft²)

$$\frac{4.1 \text{ r/hr}}{0.56 \text{ r/hr}} = 7.3$$

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Assume: a. Point source
b. 0.5 Mev average beta energy
c. $\mu = 10$ cm²/gm
d. Rate of decay follows $t^{-1.2}$

ered at the surface of an imaginary sphere at distance R from a

$$K(R) = \frac{CE\mu}{4\pi R^2} e^{-\mu R} \frac{\text{Mev}}{\text{gram}}$$

dose delivered at the surface of an imaginary sphere at distance R
average energy of beta particles
total number of disintegrations
mass absorption coefficient

$\mu = 10$ cm²/gm
$E = 0.5$ Mev

$$K(R) = 0.4 \frac{e^{-10R}}{R^2} \frac{\text{Mev}}{\text{gm-disintegration}}$$

$$K(R) = 6.9 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{millireps}}{\text{disintegration}}$$

$$K(R) = 6.4 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{millirads}}{\text{disintegration}}$$

n (3.a.) is plotted on the attached graph.
ects:

$$A_a = A_1 t_a^{-1.2}$$

integrations per unit time at time "a" after detonation
integrations per unit time at one unit of time after detonation
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$$C = 5A_1(t_a^{-0.2} - t_b^{-0.2})$$
$$C = 5A_a t_a^{1.2}(t_a^{-0.2} - t_b^{-0.2})$$

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,

$$C_\infty = 5A_a t_a$$

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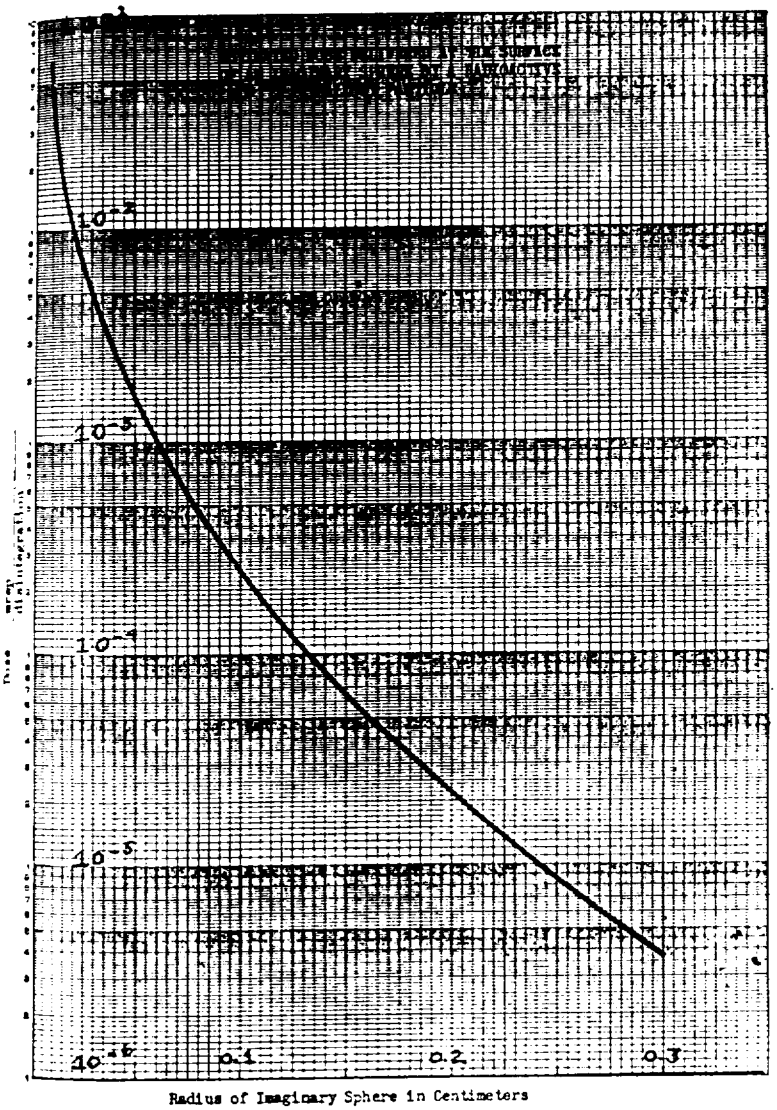
t. H. "Distributed Beta Sources in Uniformly Absorbing Media.", *Nucleonics*



Radius of Imaginary Sphere in Centimeters

APPENDIX F. ESTIMATE OF BETA DOSES FROM A SINGLE PARTICLE ON THE SKIN (POSSIBLE PRODUCTION OF RECOGNIZABLE ERYTHEMA)

Let: $t_a = 3$ hours (time particle is deposited on skin)
$t_b = 27$ hours (time particle is removed)

Assume: 1500 reps = total dose required in one day to produce recognizable erythema
0.1 cm = radius of imaginary sphere within which cells must receive 2000 reps or larger.

According to appendix E, 2.5×10^{-7} reps/disintegration is delivered to surface of imaginary sphere 0.1 centimeter in radius.

$$\frac{1.5\times10^{3}}{2.5\times10^{-7}} = 6\times10^{9} \text{ disintegrations required}$$

$$C = 5A_a t_a^{1.2}[t_a^{-1.2} - t_b^{-0.2}]$$

$$6\times10^{9} = 5A_a 3^{1.2}[3^{-0.2} - 27^{-0.2}]$$

$$A_a = 1.14\times10^{9} \text{ d/hr}$$

or about 8.6 μc at $H+3$ hours.

Of course, the radius of the imaginary sphere selected will materially affect the calculations. For example, a radius of 0.2 cm would require a particle of about 96 microcuries at $H+3$ hours to give the same dose.

APPENDIX G. ESTIMATE OF GAMMA DOSE RATE AT FOUR INCHES FROM A SINGLE PARTICLE OF FALLOUT MATERIAL

Assume:
a. The average gamma energy of fission products may be compared with radium; that the average energy of fission products is 0.7 Mev; that the average energy from radium daughters is 0.8 Mev with 2.3 photon emissions per disintegration or that the average energy per disintegration is 2.6 times greater than per disintegration of fission products.
b. A particle of 150 microcuries of beta activity or 75 microcuries of gamma activity. (See appendix H.)

$$I = \frac{8.4 \text{ mg (mc)}}{d^2} \text{ for radium through 0.5 mm of platinum.}$$

where: I = gamma dose rate (r/hr)
d = centimeters

Let: $mc = 7.5\times10^{-2}$
$d = 10$ cm

$$I = \frac{(8.4)(7.5\times10^{-2})}{10^2}$$

= 6.3 mr/hr gamma dose rate at 4 inches (for radium)

$$\frac{6.3}{2.6} \cong 2.4 \text{ mr/hr for fission products}$$

APPENDIX H. *Data and Calculations on Doses From Single Particles of Ruthenium and of Fallout Material*

A. Comparison of beta energies from Ru^{103} and Ru^{106} mixture to that from fission products.

Ru^{103} 0.3 Mev beta ($T = 42$d.)
$Ru^{106} \sim 0.03$ Mev beta ($T = 1.0$y.)
Rh^{106} 3.55 Mev beta ($T = 30$s.)

Assume: Ru^{103}/Ru^{106} ratio of 0.75 [1]

[1] All of the basic data contained herein on ruthenium is contained in HW 33068. A status report. Sept. 15, 1954.

TIMATE OF BETA DOSES FROM A SINGLE PARTICLE ON THE SKIN
POSSIBLE PRODUCTION OF RECOGNIZABLE ERYTHEMA)

(time particle is deposited on skin)
s (time particle is removed)

ps = total dose required in one day to produce recognizable erythema
cm = radius of imaginary sphere within which cells must receive 2000 reps or larger.

appendix E, 2.5×10^{-7} reps/disintegration is delivered to surface ere 0.1 centimeter in radius.

$$\frac{1.5\times10^{3}}{2.5\times10^{-7}}=6\times10^{9} \text{ disintegrations required}$$

$$C=5A_a t_a^{1.2}[t_a^{-0.2}-t_b^{-0.2}]$$

$$6\times10^{9}=5A_a 3^{1.2}[3^{-0.2}-27^{-0.2}]$$

$$A_a=1.14\times10^{9} \text{ d/hr}$$

or about 8.6 μc at $H+3$ hours.

radius of the imaginary sphere selected will materially affect the r example, a radius of 0.2 cm would require a particle of about $H+3$ hours to give the same dose.

IMATE OF GAMMA DOSE RATE AT FOUR INCHES FROM A SINGLE PARTICLE OF FALLOUT MATERIAL

average gamma energy of fission products may be compared with dium; that the average energy of fission products is 0.7 Mev; at the average energy from radium daughters is 0.8 Mev with photon emissions per disintegration or that the average energy disintegration is 2.6 times greater than per disintegration of ion products.
rticle of 150 microcuries of beta activity or 75 microcuries of nma activity. (See appendix H.)

$$\frac{\text{mg (mc)}}{d^2} \text{ for radium through 0.5 mm of platinum.}$$

I = gamma dose rate (r/hr)
d = centimeters

$$mc=7.5\times10^{-2}$$
$$d=10 \text{ cm}$$

$$\frac{.4)(7.5\times10^{-2})}{10^{2}}$$

3 mr/hr gamma dose rate at 4 inches (for radium)

4 mr/hr for fission products

and Calculations on Doses From Single Particles of Ruthenium and of Fallout Material

of beta energies from Ru^{103} and Ru^{106} mixture to that from

Ru^{103} 0.3 Mev beta (T=42d.)
Ru^{106} ~0.03 Mev beta (T=1.0y.)
Rh^{106} 3.55 Mev beta (T=30s.)
u^{106} ratio of 0.75 [1]

contained herein on ruthenium is contained in HW 33068. A status report.

To estimate a mean average energy of betas from mixture:

Parts	Isotopes	Maximum energy beta	Weighted maximum energy betas
[illegible]	Ru^{103}	0.35	0.35
[illegible]	Ru^{106}	0.04	0.05
[illegible]	Rh^{106}	13.35	4.45
Total			4.85

Average:

$$\frac{4.85}{3.66}\cong1.3$$

Average energy ~0.43 or roughly equivalent to that assumed for fission betas.
(Of course, the average energy of the betas is not the sole consideration. The spectral distribution of the betas from Rh^{106} probably is quite different from that of fission products, thus affecting the depth dose curve.)
B. Data on doses and effects from single particles of Ru^{103} and Ru^{106}:

	a	b
Size of particle	40 μ	120 μ.
Activity of particle	1.1 μc	11 μc.
Dose rate to 7 mg/cm²	6,000 rads/hr	27,500 rads/hr.
Time dose delivered	~6 days	~6 days.
2. Survey dose rate (mrads/hr)[1]	Total skin dose (rads)[2]	Effects
[illegible]	~500,000	None visible.
[illegible]	~900,000	Reddening.
[illegible]	~2,000,000	Desquamation.
[illegible]	~6,000,000	Tissue destruction.
[illegible]	~7,000,000	Tissue destruction—2 cm across. 8 mm deep.

[1] mrads/hr ~1 μc.
[2] "Total dose refers to the hot spot directly below the particle, and is valid only as to order of magnitude."

C. $\frac{750}{90}\cong8.3\ \mu c$ estimated activity of particle producing reddening effect in about 144 hours. The estimated size is 100 microns.

D. (8.3) (144) = 1200 μc total activity accounted for in the 144 hours that the dose was delivered. (Assuming constant activity during the 144 hours.)

E. What specific activity of a particle of fallout would be required to deliver the same dose in the same length of time?

The answer to this question depends upon the time after detonation that the particle comes in contact with the skin. Assuming this time to be $H+3$ hours, the specific activity would have to be about 150 μc for the same size particle.

Since the particle may be washed off before 6 days have expired, one may consider the problem another way. What must be the specific activity of a particle at $H+3$ hours to deliver this dose in the next 24 hours?

According to Strandqvist (p. 6), only about 70 percent of a 6-day dose need be delivered in one day to produce the same effect (erythema). Accepting this, then a particle with about the same activity (150 μc) at $H+3$ hours would be sufficient to deliver an erythema dose in 1 day.

F. The following data are reported for single particles collected during Upshot-Knothole and Tumbler-Snapper.

Size of particle (μ)	Activity extrapolated to H+3 hours (μc)	Distance from ground zero (miles)
(1)	1,000	[illegible]
(1)	200	[illegible]
1,626 x 924	900	[illegible]
919	480	[illegible]
723	350	[illegible]
714	400	[illegible]
555	140	[illegible]
387	250	[illegible]
231	47	[illegible]
115	5.2	[illegible]
81	3.0	[illegible]
20	.5	[illegible]

[1] Data from estimations based on radioautograph methods.

It is not intended here to imply these are the maximum specific activities per particle that existed or could exist. The data at 14.7 miles are reported to show the wide range of specific activity that may occur at one locality.

Appendix I. Estimation of Ratio of Surface Beta Dose Rate to Gamma Dose Rate at 4 Inches From an Object 2 Inches in Radius

One may assume a ratio of beta dose rate (at 7 mg/cm² depth of skin) to gamma dose rate (3 feet above the ground) of 125:1. If a contaminated object of say 2-inch radius were removed (or shielded) from a general radiation field the gamma dose rate at 4 inches from the surface might be some 40 times less than from an infinite plane with the same degree of contamination (appendix D), while the beta dose rate might remain almost the same value if the object is in contact with the skin. Thus, the beta-to-gamma dose rates measured under these conditions might be 5,000:1. For other than a plane surface, the gamma dose rates might be higher, thus reducing this ratio.

of particle (μ)	Activity extrapolated to H+3 hours (μc)	Distance from ground zero (miles)
	1,000	[illegible]
	200	[illegible]
	900	[illegible]
	490	[illegible]
	350	[illegible]
	400	[illegible]
	140	[illegible]
	250	[illegible]
	47	[illegible]
	5.2	[illegible]
	3.0	[illegible]
	.5	[illegible]

n radioautograph methods.

e to imply these are the maximum specific activities or could exist. The data at 14.7 miles are reported of specific activity that may occur at one locality.

OF RATIO OF SURFACE BETA DOSE RATE TO GAMMA NCHES FROM AN OBJECT 2 INCHES IN RADIUS

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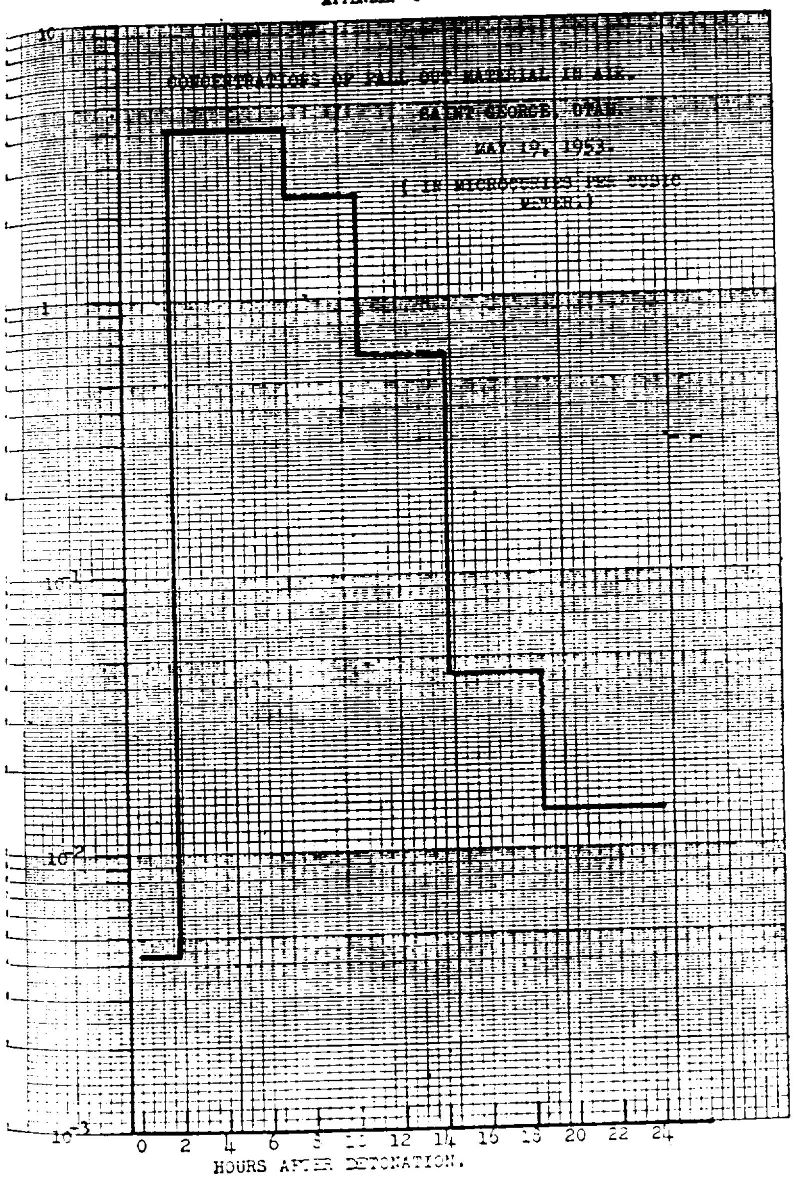
APPENDIX "J"



APPENDIX K. METHOD USED IN ESTIMATING DOSES TO THE LUNGS FROM INHALATION OF FALLOUT MATERIAL

Assumptions

The following assumptions are made in estimating radiation doses to the lungs.

A. Twenty percent of the inhaled activity is deposited.

B. There will be no elimination of particles during their radioactive lifetimes. There is uncertainty as to the biological half life of particles in the lungs. In those communities showing the highest concentrations of fallout, the peak of airborne material (which accounted for the greatest percentage of total fallout) occurred only a few hours after detonation. If one assumes a radiological decay according to $t^{-1.2}$ and a biological half life of say 30 days, the omission of biological half life would not affect seriously the computed total dose.

C. All of the activity is associated with particles in the respirable range of sizes. Past data from cascade impactors indicate that about 90 percent of the activity is associated with particles 5 microns or less in the communities surrounding the Nevada test site.

D. The lungs are uniformly irradiated.

E. The weight of the lungs is 900 grams.

F. An individual inhales 20 cubic meters per 24 hours.

G. The average beta energy is 0.5 Mev.

H. The gamma dose is negligible compared to the beta dose.

Data at St. George, Utah

(Short time) 0505	Duration	Approximate mid-point after detonation	[1]$\mu c/M$	μc Inhaled (col. II times col. IV times 0.834)	μc Retained (col. V times 0.2)
(I)	(II)	III	(IV)	(V)	(VI)
	Hours	*Hours*			
0610 to 1130	4.3	3	4.17	15.0	3.0
1130 to 1445	3.2	8	2.38	6.3	1.3
1445 to 1845	4.0	11.5	6.3×10^{-1}	2.1	[illegible]
1845 to 2300	4.2	15.6	4.4×10^{-2}	0.15	[illegible]
2300 to 0635	7.5	21.5	1.4×10^{-2}	0.09	[illegible]
[1] 0635 to 1835	12.0	31.5	1.4×10^{-2}	0.14	[illegible]

[1] Assumed.

Sample calculations

$$D=5At_a^{1.2}[t_a^{-0.2}-t_b^{-0.2}]$$

Let: $t_a=3$ hours
$t_b=2184$ hours (13 weeks)
$A=3\ \mu c$

$$D=(5)(3\times2.22\times10^{6}\times60)(3)^{1.2}[3^{-0.2}-2184^{-0.2}]$$

$=4.4\times10^{9}$ disintegrations from 3d hour to 13th week.

Assume: $E_{avg.}=0.5$ Mev

$$(4.4\times10^{9})(0.5)(1.6\times10^{-6})\left(\frac{1}{900}\right)\left(\frac{1}{39}\right)=4.2\times10^{-2}\text{ reps}$$

$=42$ mreps

Total lung dose for 13 weeks: $\sim$130 mreps.

ED IN ESTIMATING DOSES TO THE LUNGS FROM IN[illegible]
ATION OF FALLOUT MATERIAL

ns are made in estimating radiation doses to the

nhaled activity is deposited.
nation of particles during their radioactive life[illegible]
the biological half life of particles in the lung[illegible]
the highest concentrations of fallout, the peak of
accounted for the greatest percentage of total[illegible]
ours after detonation. If one assumes a radiological
l a biological half life of say 30 days, the omission
not affect seriously the computed total dose.
associated with particles in the respirable range of
ade impactors indicate that about 90 percent of the
particles 5 microns or less in the communities [illegible]
e.
y irradiated.
is 900 grams.
) cubic meters per 24 hours.
y is 0.5 Mev.
ligible compared to the beta dose.

Data at St. George, Utah

	Duration (II)	Approximate midpoint after detonation III	$^{8}\mu c/M$ (IV)	μc Inhaled (col. II times col. IV times 0.834) (V)	[illegible] (col. [illegible] times [illegible]) (VI)
	Hours	*Hours*			
	4.3	3	4.17	15.0	[illegible]
	3.2	8	2.38	6.3	[illegible]
	4.0	11.5	6.3×10^{-1}	2.1	[illegible]
	4.2	15.6	4.4×10^{-2}	0.15	[illegible]
	7.5	21.5	1.4×10^{-2}	0.09	[illegible]
	12.0	31.5	1.4×10^{-2}	0.14	[illegible]

Sample calculations

$) = 5At_a^{1.2}[t_a^{-0.2} - t_b^{-0.2}]$

$_a = 3$ hours
$_b = 2184$ hours (13 weeks)
$= 3\ \mu c$

$\times 10^6 \times 60)(3)^{1.2}[3^{-0.2} - 2184^{-0.2}]$

integrations from 3d hour to 13th week.

ssume: $E_{avg.} = 0.5$ Mev

$(1.6\times10^{-6})\left(\frac{1}{900}\right)\left(\frac{1}{39}\right) = 4.2\times10^{-2}$ reps

$= 42$ mreps

ks: ~130 mreps.

APPENDIX L. ESTIMATE OF DOSE AT SURFACE OF IMAGINARY SPHERE 1 MILLIMETER IN RADIUS

Assume: Average activity for 30 minutes is 0.5 μc at H+3 to H+3½ hours. (See reference appendix H.)

Then: $0.5\times2.2\times10^6\times30 = 3.3\times10^7$ disintegrations/30 minutes.

At surface of imaginary sphere 1.0 mm. in radius the dose rate from a point source is

$$2.52\times10^{-4}\frac{\text{mreps}}{\text{disintegration}}$$ (See appendix E.)

$$(3.3\times10^7)(2.52\times10^{-4}) = 8.3\times10^3 \text{ mreps/30 min.}$$
$$\cong 8 \text{ reps/30 min.}$$

For particles of higher specific activity, the dose would be correspondingly higher, of course.

APPENDIX M

Estimate of Sr^{90} in soils of Pacific islands

Location	Total activity ($\mu c/ft^2$) (measured) I	Sr^{89}-Sr^{90} ($\mu c/ft^2$) (measured) II	Rough estimate external infinity gamma dose (roentgens) III
[illegible]	1.2×10^{-1}	8.7×10^{-3}	4
[illegible]	3.0×10^{-1}	1.2×10^{-2}	4
[illegible]	1.0	3.8×10^{-2}	12
[illegible]	1.1	2.8×10^{-2}	8
[illegible]	3.2×10^{-1}	1.1×10^{-2}	4
[illegible]	1.6×10^{-1}	4.8×10^{-3}	2
[illegible]	7.8×10^{-2}	1.3×10^{-3}	0.5
[illegible]	62.0	1.08	500
[illegible] (Northern)	40.0	5.5×10^{-1}	500
[illegible] (Central)	5.0	5.3×10^{-1}	500
[illegible] N. Village)	4.5	9.2×10^{-1}	500
[illegible] (Western)	230.0	12.5	4,500
[illegible]	50.0	1.2	1,500
[illegible]	200.0	4.9	3,300
[illegible]	53.0	9.8×10^{-2}	60
[illegible]	3.3	4.4×10^{-1}	250
[illegible]	8.0	6.6×10^{-1}	400
[illegible]	6.1×10^{-1}	9.6×10^{-2}	170

All data as of May 5, 1954, except island of Eriirippu where date is May 20, 1954.

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington D. C., August 2, 1957.

Hon. CHET HOLIFIELD,
Chairman, Special Subcommittee on Radiation,
Joint Committee on Atomic Energy,
Capitol Building, Senate Post Office, Washington, D. C.

DEAR MR. HOLIFIELD: As a part of the written record of The Nature of Radioactive Fallout and Its Effects on Man, there is being reproduced a document Discussion of Radiological Safety Criteria and Procedures for Public Protection at the Nevada Test Site written by me some time ago. I would greatly appreciate it if a footnote (attached) were added to this document.

Also enclosed is a copy of the revised radiological safety criteria (April 1957) that are currently being used. I would like to suggest respectfully that these revised criteria also be printed so that the reader may have the benefit of our latest thinking on these matters.

Sincerely yours,

GORDON M. DUNNING,
Health Physicist, Division of Biology and Medicine.

RADIOLOGICAL SAFETY CRITERIA DURING NUCLEAR WEAPONS TESTING AT THE NEVADA TEST SITE

(April 1957)

INTRODUCTION

The criteria and procedures set forth in the following paragraphs were established after full consideration for protecting the health and welfare of the public, both in terms of radiological exposure as well as possible hazards, hardships or inconveniences resulting from disruption of normal activities. Criteria are established as guides for the Test Organization in determining whether any special actions should be taken to protect the public.

These criteria are not established with the expectation that the coming tests at the Nevada Test Site actually will result in radiation levels which will be greater than heretofore. Rather, they formalize past criteria to give even clearer guides for protecting the public. With improved methods of predicting fallout and with the use of balloons and higher towers for detonating the nuclear devices, it is expected that fallout in populated areas from future tests at the Nevada Test Site will be less than the highest amounts which have occurred in the past.

Two basic assumptions are made in this report:

(a) It is the responsibility of the Division of Biology and Medicine to establish such criteria for the Atomic Energy Commission as deemed necessary to protect the health and welfare of the general populace from consequences of weapons tests conducted at the Nevada Test Site.

(b) The operational procedures adopted for meeting these criteria shall be the responsibility of the Test Manager, as directed by the Division of Military Application, with the technical guidance of the Division of Biology and Medicine.

The following criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified herein.

SECTION I. EVACUATION

BACKGROUND

The decision to evacuate a community is critical for two principal reasons. One, presumably there might be a health hazard if the personnel were allowed to remain. Two, there is always an element of danger and/or hardship to personnel involved in such an emergency measure.

It is recognized that extenuating circumstances may accompany any situation where conditions indicate evacuation as a mode of action. The size of the community, areas and accommodations available for the evacuees, weather conditions, means of transportation and routes of evacuation, disposition of ambulance cases, protection of the property left behind, and many other factors may enter into the decision relative to evacuation. Further, it is recognized that under certain conditions, the evacuation of a community might prove not only rather ineffectual but could result in more radiation exposure than if the population remained in place unless the situation be adequately evaluated. A blanket evaluation cannot be made in advance; each situation can be unique. The following criteria therefore are suggested as guides in assessing the possible radiological hazards; the final decision must be made on the basis of all relevant factors known at the time. They are intended to apply principally to relatively large populations since small groups may be evacuated without equivalent potential hazards.

Owing to the necessity of making early measurements and decisions, it is to be expected that dose-rate readings, taken with survey meters, will be the available evidence at the times of concern. This necessitates making rough approximations in advance of the effects of weathering and of shielding from normal housing, in reducing the radiation exposure. The variable nature of these two parameters makes impossible the establishment of a precise rule covering all situations. Therefore, the following may be used in making conservative estimates of these effects:

(a) For weathering—the measured gamma dose rates at three feet above the ground be assumed to decay according to $(t)^{-1.2}$ for the first week after a detonation, $(t)^{-1.8}$ for the second week, and $(t)^{-1.4}$ thereafter.[1]

(b) For shielding—the accumulated dose per day be 25% less than the outdoors dose.[2]

In the case of a truly emergency situation where potential hazards may exist either from the fallout or from mass evacuation of large populations, it would seem proper than due consideration be given to the biological repair process that takes place with radiation doses distributed in time (recognizing that such effects from radiation as genetic changes and life shortening may not be time dependent). The estimates for biological repair for man are quite uncertain so a conservative value is used here of a half-time of repair of about four weeks.

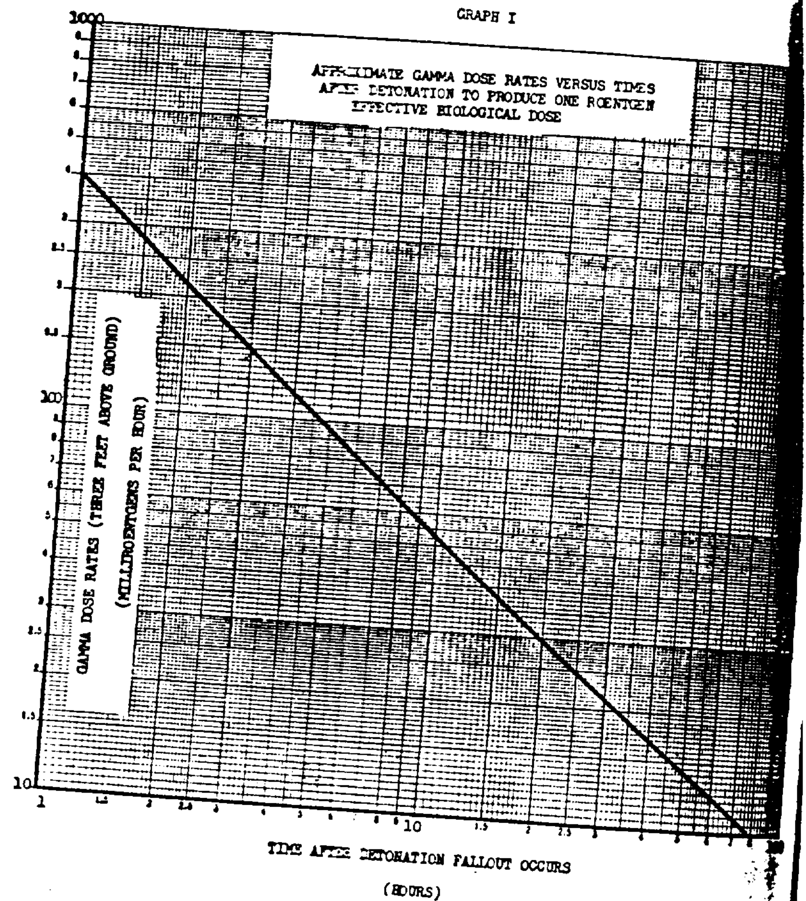
Graph I incorporates the above factors of weathering, shielding, and biological repair into a single curve. This graph may be linearly extrapolated to other dose rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 10 r per hour, then about 67 r (effective biological dose) may be accumulated, i. e., $\frac{10}{0.15} \times 1.0 = 67$

---

[1] This concept was suggested after analyzing data from both the Nevada Test Site and the Eniwetok Proving Ground and is intended to give generalized estimates to cover a wide variety of situations. It is recognized that with the smaller fallout patterns and over the sandy soils around the Nevada Test Site, the effective decay constants may be greater than these. An expanded monitoring program will be in operation during Operation Plumbbob (1957 Series) for the collection of pertinent data to allow better estimates of effective rates and of the efforts of shielding provided by buildings.

[2] This is based on an average 12 hours per day stay in a frame house having an attenuation factor of two. It is recognized that some individuals will be in buildings having greater attenuation factors, and for longer periods of time. On the other hand, this is generally an area where people may live an appreciable amount of time out of doors and where windows and doors are left open, so the fallout material may enter the buildings. Possible revision of these estimates will await results from the expanded monitoring program during Operation Plumbbob.

GRAPH I



CRITERIA I

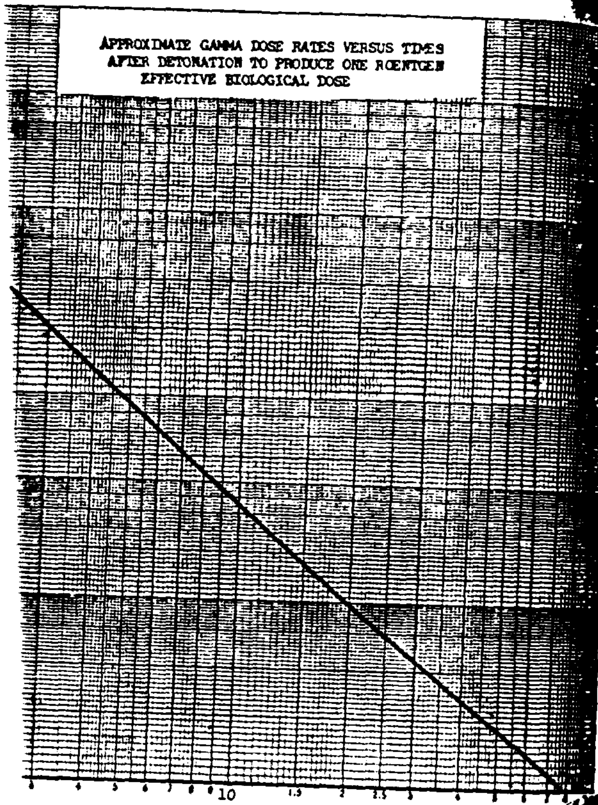
Effective Biological Doses may be calculated according to Graph I.

Table I may be used in evaluating the feasibility of evacuating relatively large populations.

TABLE I.—*Radiological criteria for evaluating feasibility of evacuation*

Effective biological dose:	Maximum effective biological dose that must be saved by act of evacuation (otherwise evacuation will not be indicated):
Up to 30 roentgens	(No evacuation indicated.)
30 to 50 roentgens	15 roentgens.
50 roentgens and higher	(Evacuation indicated without regard to quality of dose that might be saved, providing adequate shelters are not available and the estimated hazards concomitant with evacuation are acceptable.)

GRAPH I



TIME AFTER DETONATION FALLOUT OCCURS

(HOURS)

CRITERIA I

Doses may be calculated according to Graph I.
ed in evaluating the feasibility of evacuating relatively

ogical criteria for evaluating feasibility of evacuation

-e:	Minimum effective biological dose that must be saved by act of evacuation (otherwise evacuation will not be indicated):
-----------	(No evacuation indicated.)
-----------	15 roentgens.
:her-------	(Evacuation indicated without regard to quality of dose that might be saved, providing adequate shelters are not available and the estimated hazards concomitant with evacuation are acceptable.)

SECTION II. PERSONNEL REMAINING INDOORS

BACKGROUND

By remaining indoors (*a*) the gamma exposure will be reduced, and (*b*) there is less possibility that the fallout material will come into contact with the skin. (Beta burns have occurred in the past only when the fallout material has remained in direct contact with the skin.) To prevent or greatly reduce this latter effect, it is highly desirable to make decisions before or very shortly after the start of the fallout. Likewise, partial shielding at these early times will be of optimum benefit due to the relatively high gamma dose rates. Thus, the decisions must be based on predicted fallout in an area, or on dose-rate readings from field monitors' reports.

These predictions are of course subject to varying degrees of uncertainly so that personnel may be asked to remain indoors unnecessarily. On the other hand decisions and action must be taken relatively quickly if optimum benefits are to be derived and remaining indoors until the radiological information is more accurately evaluated probably represents one of the easiest and effective ways of meeting an emergency situation.

Due to uncertainties in our knowledge, and recognizing the usual unequal distribution of fallout, it has not been possible to establish precisely the amount of fallout in an area that could produce beta burns. The Marshallese experience showed such effects for those people exposed to 175 r and 69 r whole body gamma radiation, but none for those individuals on the Island of Utirik (370 miles from ground Zero) receiving 14 roentgens. Whether these results would hold true for other situations is not known, i. e., different particle size distribution, different type skin, etc. At one location, Riverside Cabins, Nevada, about 15 people were in an area receiving fallout in an amount equivalent to infinity dose of 15 roentgens, with no known cases of beta burns, although it is not known if anyone was out-of-doors during the time of fallout. Until more is learned of this phenomenon, it would appear advisable to remain out of the direct fallout when the amount would be such as to produce about 10 roentgens gamma infinity dose as measured at three feet above the ground. In the event personnel are out of doors during the time of this amount of fallout, the possibility of beta burns could be greatly reduced by the simple expedient of changing clothing and of bathing.

If people were not asked to remain indoors during the period of highest dose rates in an area where the infinity dose was 10 roentgens or more, their actual exposure might be in excess of 3.9 roentgens of wholebody gamma. This would not necessarily be hazardous but would exceed the established criteria for Plumbbob (Criteria VI).

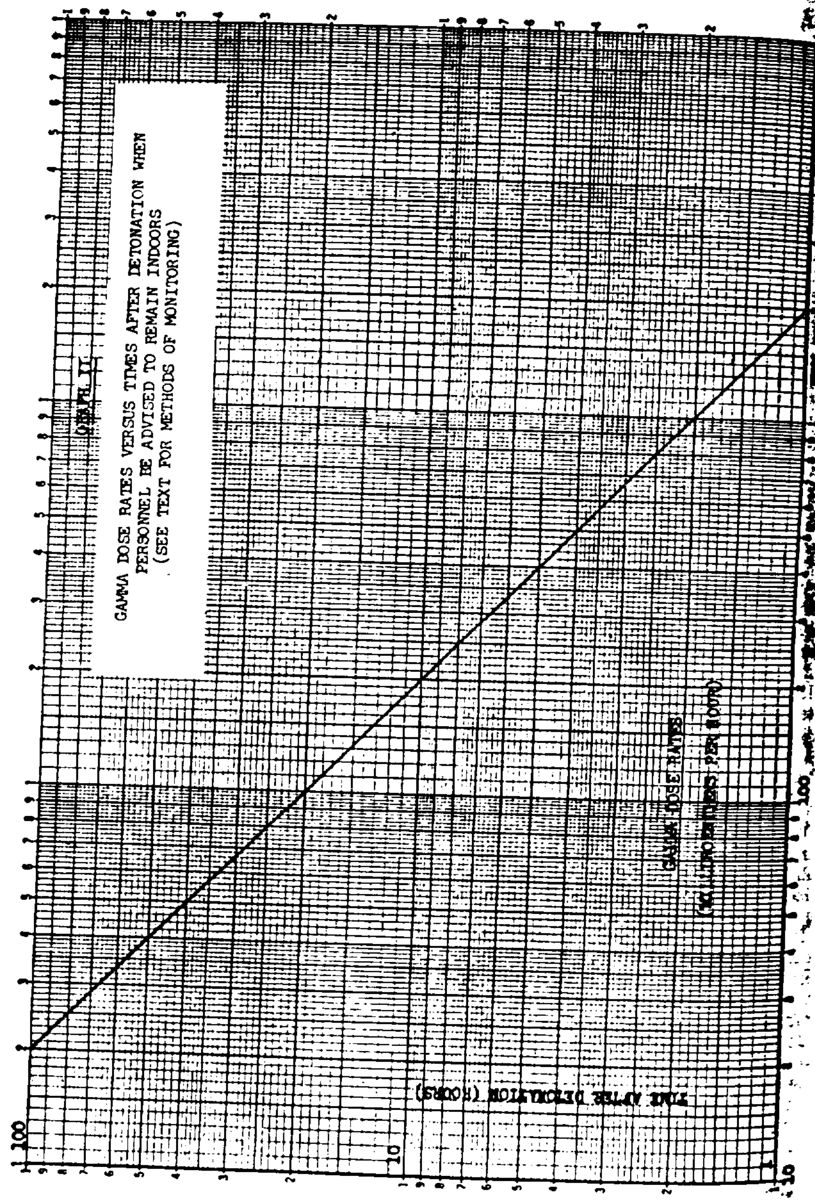
CRITERIA II

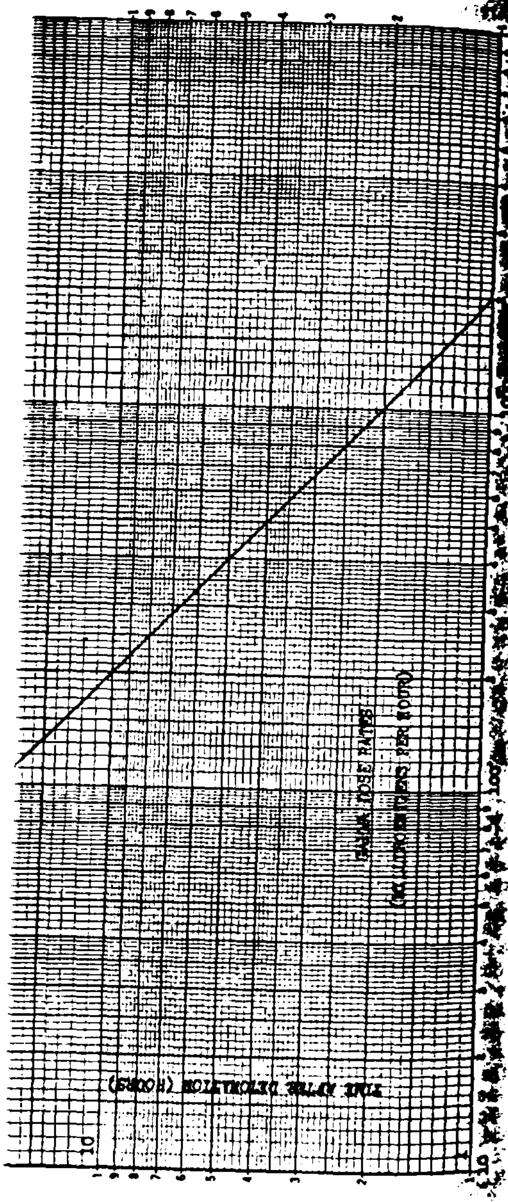
When the gamma dose rate reading as measured by a survey meter held three feet above the ground reaches the values given in Graph II at the times indicated, it is recommended that personnel be requested to remain indoors with windows and doors closed. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

In the event that there be convincing evidence that the radiation levels given in the graph will be reached, it is recommended that personnel be requested to remain indoors BEFORE fallout occurs or before the radiation levels equal those in Graph II. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

It is recommended that people who had been out of doors during fallout of the above magnitude or greater be advised to change clothing and to bathe. The clothing may be cleaned by normal means. While bathing, special attention should be paid to the hair and any exposed parts of the body.

In the event that the monitoring takes place AFTER the fallout has occurred, and extrapolation of the dose rate readings equals or exceeds those in Graph II at the estimated time of fallout, then it is recommended that the same advice be given as in the preceding paragraph.


GRAPH II
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION WHEN
PERSONNEL BE ADVISED TO REMAIN INDOORS
(SEE TEXT FOR METHODS OF MONITORING)
GAMMA DOSE RATES
TIME AFTER DETONATION (HOURS)
100
10
1000



Section III. Decontamination of Personnel

BACKGROUND

The principal purposes for decontaminating personnel are to reduce the potential beta doses to the skin, and to a lesser degree reduce the external gamma exposure. The discussion on beta doses in Section II is applicable here. In addition, there is much unknown about monitoring methods for personnel contamination. The following criteria were previously developed on the basis of measuring the gamma radiations (and then extrapolating to the accompanying beta radiations) with existing instruments. Recently new field instruments have been developed for direct beta measurement, but there remains considerably more work necessary to calibrate them in terms of beta dose rates to the body. Until this is accomplished, the past criteria may be used.

CRITERIA III

Where it is not possible to monitor personnel outside of a general radiation field, it is recommended that an estimate be made of the degree of personnel contamination by determining the location of the individual at the time of fallout. In the event there is uncertainty as to the validity of such an estimate, the assumption will be made that the individual was out-of-doors during the time of fallout. In those areas where the infinity gamma dose equals or exceeds 20 roentgens, it is recommended that the individual be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field where personnel contamination exists over relatively large areas of the EXPOSED body (one-half square foot or more):

When the reading of a survey instrument held with the center of the probe or center of the ionization chamber four inches from the center of the contaminated area, equals or exceeds the values given in Graph III it is recommended that personnel be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field, where personal contamination exists over relatively small areas of the EXPOSED body (less than one-half a square foot):

The recommended maximum values are one-half those given in Graph III. Monitoring of the head, arms, hands, lower legs, and feet will be considered as coming under this category. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated, unless the radiation levels exceeds those stated below concerning monitoring of exterior surfaces of clothing.

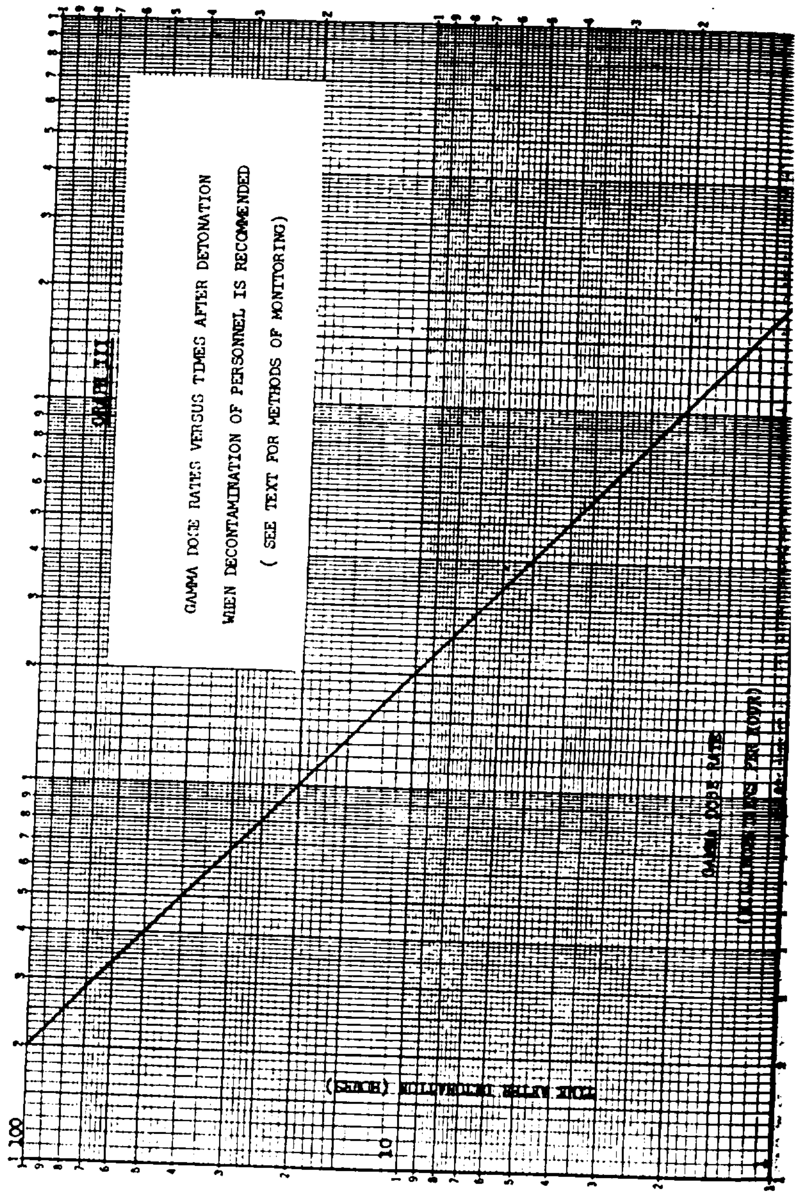
For personnel being monitored outside the general radiation field, and the contamination exists over only spots of EXPOSED body (about the size of a half-dollar or less):

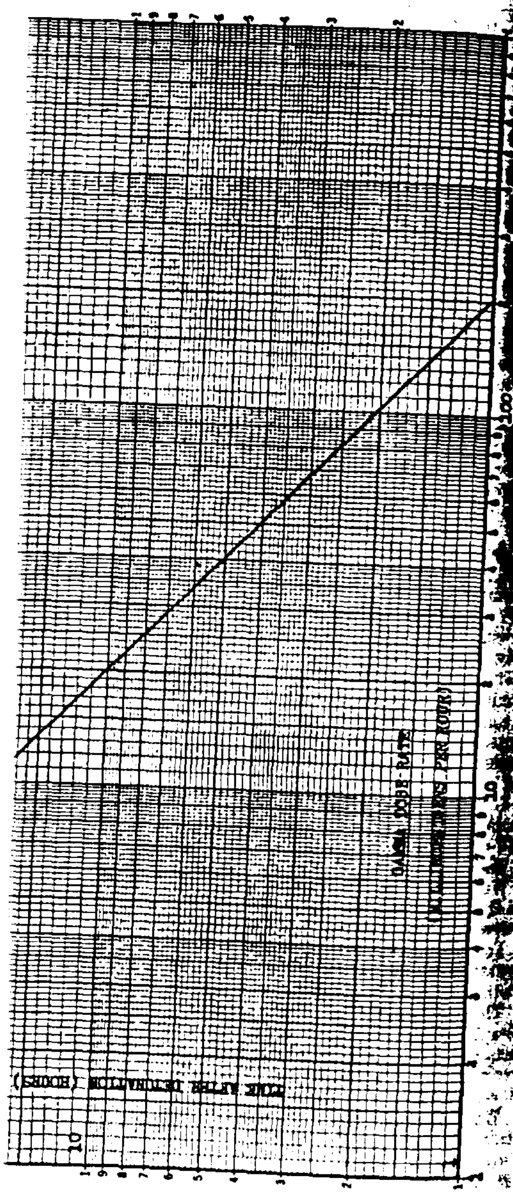
The recommended maximum values are one-fifth those given in Graph III. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field and the contamination exists over any size area on the exterior surface only of the clothing:

The recommended values under these conditions are twice those given in Graph III. The first recommended action shall be to resort to such simple acts as brushing off the clothing. If this action does not reduce the radiation levels to twice those given in Graph III or less, then personnel should be advised to change clothing and to bathe.

When the general contamination of a community is of the degree to produce an estimated maximum theoretical infinity gamma dose of 20 roentgens or greater, personnel who have been out-of-doors at any time during the first two days and generally moving around in the area (as apposed to such an act as walking only between a building and a vehicle) should be advised to brush off the footwear (outdoors), to bathe and to change clothing as soon as possible after the final return indoors each day. In addition personnel who go out-of-doors for any length of time during the first two days after such a fallout should be advised to wash their hands at least after the final return indoors each day, and more frequently, if possible.


GRAPH III
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL IS RECOMMENDED
(SEE TEXT FOR METHODS OF MONITORING)
GAMMA DOSE RATE
100
10



SECTION IV. DECONTAMINATION OF MOTOR VEHICLES

BACKGROUND

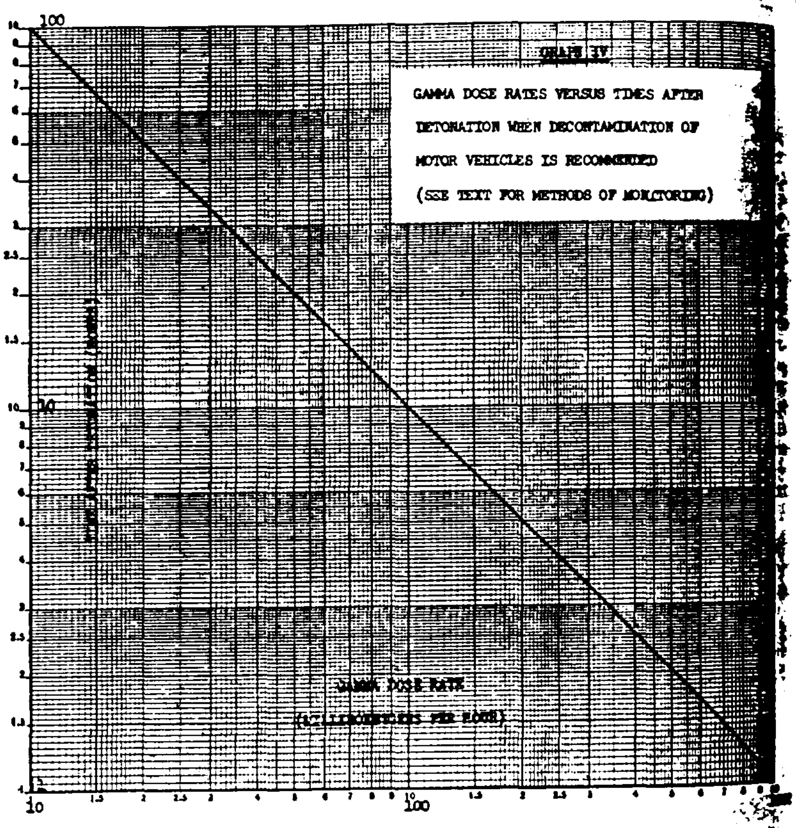
The principal purposes for decontaminating motor vehicles are to reduce the potential beta doses to the skin by contact with the vehicle, and to reduce the external gamma exposure. All of the uncertainties inherent in personnel monitoring are applicable here plus additional ones, such as estimates of the probability of contact and the amount of transfer of radioactive material from the vehicle to the skin. The following criteria for monitoring motor vehicles (Graph IV) were previously developed, and until the new beta measuring instruments (see Section III) are calibrated, will continue to be recommended.

One method of avoiding or significantly reducing vehicle contamination is to prevent their being in an area during the time of actual fallout. It is possible that fallout across a highway may be higher than that permitted for populated areas. When such a condition is predicted, it would be advisable to hold vehicular traffic until after the fallout had essentially ceased. Past experience has shown that very significantly less vehicle contamination occurs when it passes through an area afterwards compared to being present during the fallout time, although appreciable amounts can still be picked up on the tires and under the fenders. Obviously, there is not a precise value that may be given, but it is recommended that if the amount of fallout across a main highway is predicted to be in an amount equivalent to 10 roentgens or greater infinity dose, that traffic be temporarily halted until the fallout has essentially ceased.

CRITERIA IV

It is recommended that when the predicted fallout across a main highway be equivalent to 10 roentgens or greater infinity gamma dose, vehicles be held until the fallout has essentially ceased

Graph IV may be used in determining the advisability of decontaminating motor vehicles. The survey instrument should be held with the center of the probe or center of the ionization chamber four inches from any readily accessible surface.



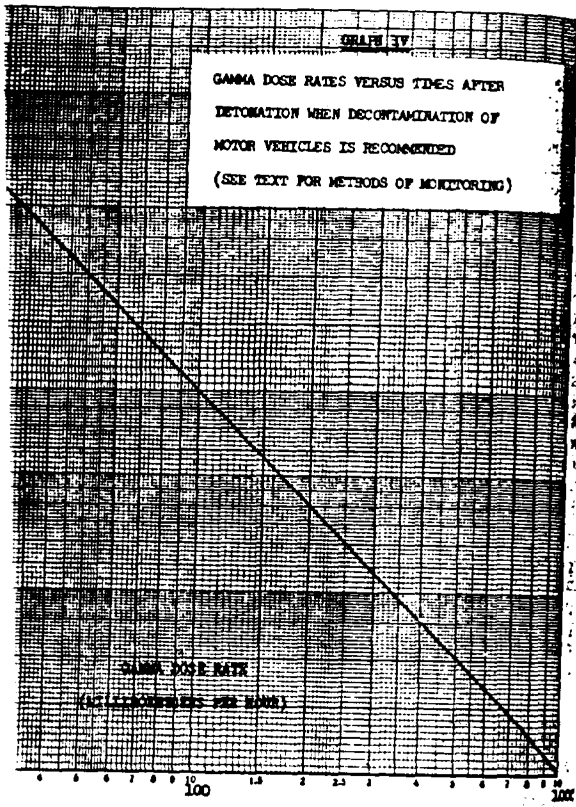
Section V. Contamination of Water, Air and Foodstuffs

BACKGROUND

In any area where the theoretical gamma infinity dose exceeds 10 roentgens, adequate sampling of the water, air, and foodstuffs should be made to ascertain the conditions of possible contamination, if for no other reasons than as precautionary and documentary measures. Based on past data, however, it is not expected that under those conditions of fallout where the radiation levels are below those stipulated for possible evacuation, that the degree of contamination would be a health hazard. Nor is it implied here that any level above this does constitute a serious contamination of water, air, or foodstuffs. One good point of reference is the Marshallese experience where the whole-body gamma exposure was 175 roentgens yet the internal deposition from ingestion and inhalation was relatively small. In the event of a relatively heavy fallout, but less than one calling for evacuation, a common sense rule would be to wash exposed foods, such as leafy vegetables, since this is the most probable mode of intake of activity.

CRITERIA V

Monitoring of air, fod and water should be made as soon as possible in areas where the infinity dose equals or exceeds 10 roentgens. There need be no restrictive action imposed on food and water intake in areas where the fallout is less than that calling for evacuation. Washing off of such exposed foods as leafy vegetables may be advised when such action seems desirable.



CONTAMINATION OF WATER, AIR AND FOODSTUFFS

BACKGROUND

ıe theoretical gamma infinity dose exceeds 10 roentgens, ıe water, air, and foodstuffs should be made to ascertain le contamination, if for no other reasons than as precau- ry measures. Based on past data, however, it is not se conditions of fallout where the radiation levels are be- r possible evacuation, that the degree of contamination d. Nor is it implied here that any level above this does tamination of water, air, or foodstuffs. One good point iallese experience where the whole-body gamma exposure ıe internal deposition from ingestion and inhalation was event of a relatively heavy fallout, but less than one ı common sense rule would be to wash exposed foods, s, since this is the most probable mode of intake of

CRITERIA V

and water should be made as soon as possible in areas quals or exceeds 10 roentgens. There need be no re- on food and water intake in areas where the fallout for evacuation. Washing off of such exposed foods advised when such action seems desirable.

SECTION VI. ROUTINE RADIATION EXPOSURES

BACKGROUND

The Atomic Energy Commission has adopted, as an operational guide, 3.9 roentgens whole body external gamma radiation for off-site exposure resulting from Operation Plumbbob.

The discussion in Section I on effects of weathering and shielding on determining the actual radiation exposure is applicable here. However, the factor of biological repair is not considered for routine exposures. This factor bears on somatic effects and may justifiably be considered in emergency situations when it is necessary to weigh the relative hazards from radiation versus mass evacuation. However, for routine exposures, the actual (estimated) roentgen dose should be used. To distinguish from the Effective Biological Dose and the Infinity Dose, this exposure will be expressed as the Estimated Dose.

Graph V incorporates the assumed effects of weathering and of shielding according to the discussion in Section I. The graph may be linearly extrapolated to other dose-rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 360 milli-roentgens per hour, then about three roentgens (estimated dose) may be accumulated, i. e., $\frac{360}{120} \times 1 = 3$.

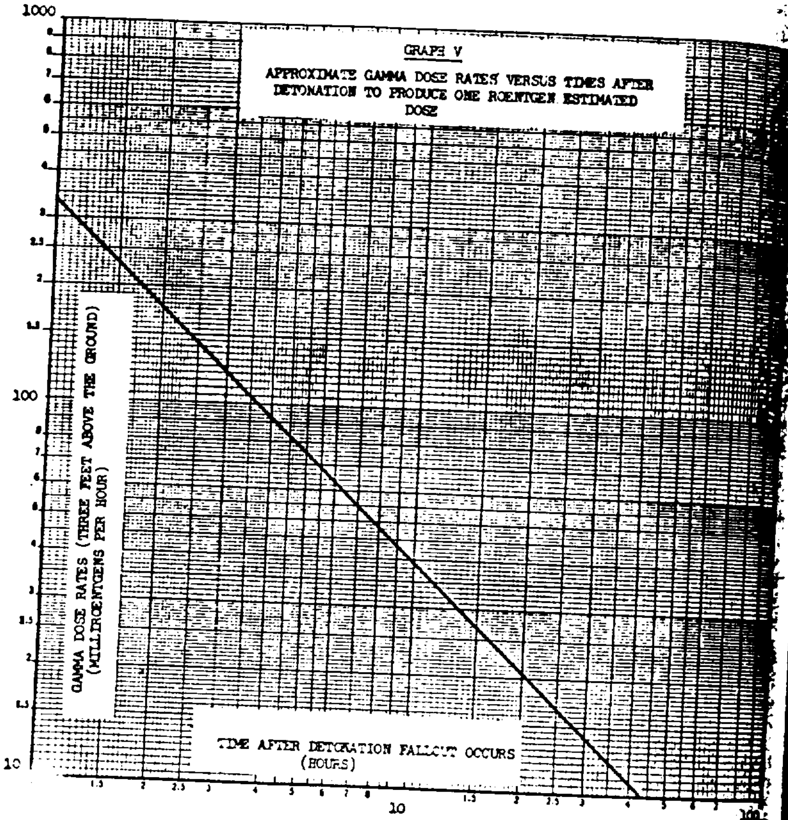
As discussed in Section I, the estimates of the effects of weathering and of shielding may be conservative for areas around the Nevada Test Site. A range of radiation doses is to be expected for these people since they will not all be living under identical conditions. The radation doses estimated by the present method is expected to fall within and toward the upper end of such a range. The information obtained from the expanded radiological monitoring program for Operation Plumbbob, should yield refinements in the method of estimating the radiation exposures.

In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

CRITERIA VI

Estimated Doses may be determined according to Graph V. In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

The whole-body gamma Estimated Dose for off-site populations should not exceed 3.9 roentgens resulting from Operation Plumbbob. This total dose may result from a single exposure or series of exposures.



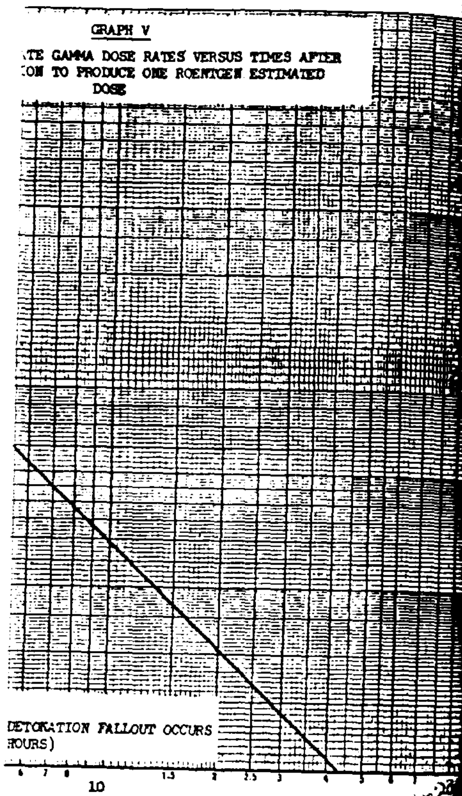
Representative HOLIFIELD. This afternoon we will have Dr. Forrest Western, Division of Biology and Medicine, Atomic Energy Commission; Dr. Lyle Alexander, Department of Agriculture; and Dr. Roger Revelle, Scripps Institute of Oceanography, as witnesses.

We will meet in the Senate caucus room, room 318, at 2 p. m.

Before we recess, I have several statements to insert in the record at this point. The first is a statement of the United States Naval Radiological Defense Laboratory concerning the prediction, measurement and analysis of fallout and radiological countermeasures. Next a statement by LeRoy H. Clem, of Headquarters, Air Weather Service, United States Air Force. The third is a statement by Col. B. G. Holzman, and Col. Norair M. Lulejian, of the Air Force Research and Development Command, fourth is a statement by Dr. Donald M. Swingle, of the Army Signal Corps, Evans, South Carolina Laboratory, and finally a presentation submitted by James G. Terrill, Jr., Chief, Radiological Health Program, Public Health Service.

STATEMENT OF UNITED STATES NAVAL RADIOLOGICAL DEFENSE LABORATORY
PREDICTION OF FALLOUT

It was realized after the early weapons test operations that there existed a requirement for predicting the then little understood phenomenon of fallout. NRDL made the first studies on this subject by employing scaling techniques (1, 2, 3) similar to the approach used in the determination of blast and thermal



This afternoon we will have Dr. Forre
y and Medicine, Atomic Energy Commi
partment of Agriculture; and Dr. Rog
Oceanography, as witnesses.
caucus room, room 318, at 2 p. m.
everal statements to insert in the reco
statement of the United States Nav
tory concerning the prediction, measur
and radiological countermeasures. Ne
em, of Headquarters, Air Weather Ser
. The third is a statement by Col. B.
M. Lulejian, of the Air Force Resear
fourth is a statement by Dr. Donald
Corps, Evans, South Carolina Labor
ion submitted by James G. Terrill, Jr
rogram, Public Health Service.

NAVAL RADIOLOGICAL DEFENSE LABORATORY
CTION OF FALLOUT

weapons test operations that there existed
then little understood phenomenon of fallou
this subject by employing scaling technique
used in the determination of blast and therm

effects for weapons over a wide range of yields. Such scaling of radiological phenomena resulted in satisfactory results when compared to the meager experimentally determined field data (4). As more effects data became available from subsequent weapons test operations (5, 6, 7, 8) the limitations of a straightforward scaling technique were observed and the increasing dependence of the fallout on the dynamical parameters involved, such as the meteorological variables, became apparent. This led to the development of a physical model that would hopefully explain the mechanism of fallout such that given the required input parameters a knowledge of the fallout phenomenology for any type of nuclear detonation could be predicted (2, 9, 10). This model development was initiated by concentrating the effort on surface land detonations. Very little factual data were available for construction of such a model. However, it was realized that this approach offered the most positive chance of success and consequently theoretical assumptions regarding the model input parameters would have to be made. This model then defined the cloud source and associated parameters such as particle size distribution and relation of activity to particle size. A mechanism theory based on the particle settling rates and the effect of the winds aloft in determining the trajectories of these particles was established. A mathematical technique of summing the deposited activity on the earth's surface was developed such that the fallout pattern would then be established.

Because of the many initial assumptions made a great deal of effort was taken in subsequent nuclear weapons test operations to obtain refinements of these parameters by measurement (2). This work included detailed physical, chemical and radiochemical analyses of fallout particles, time dependent studies on the fallout such as time of arrival as a function of distance, rate of arrival, and time to peak activity. Activity levels as a function of distance were made (5, 6, 7). Rockets were employed to establish the radioactivity profiles within the mushroom cloud (11). Such experimental data were employed in the refinement of the physical model as well as were detailed studies of the effect of time and space variation of the winds aloft on the trajectories of the fallout particles. This data greatly improved the ability of the model to predict the fallout and continuing refinements are being made. The use of a physical model for understanding and predicting fallout appears justified (12).

A fallout forecasting technique has been developed to satisfy the immediate needs of the military. This technique employs many of the model parameters established. However it was designed for operational use and predicts only the perimeter of the fallout pattern and the radiological axis of the area or "hot line" (13, 14). It is a rapid system that was tested at Operation Redwing and proved very satisfactory for both surface land and surface water detonations. The details of this technique are described in the enclosed NRDL Technical Reports TR-127 and TR-139.

There has not been developed a satisfactory physical model for underwater or underground detonations to date. For these cases and environmental conditions other than surface or near surface burst the use of scaling techniques holds the best promise. However it is not inconceivable that the mechanism of such detonations will be understood and subsequent models developed.

The accuracy of prediction of fallout is very dependent on the quality of the meteorological data available. With precise meteorological data the area of fallout and direction of the axis of the pattern can be excellently forecast. The quantitative prediction of radiation levels at any point within the fallout area is much more difficult to predict.

It is considered essential in order to insure the application of fallout prediction technique and radiological hazard assessment to a wide variety of detonation conditions that the basic mechanisms responsible for formation of fallout, movement of fallout material in atomic clouds, its dispersal by meteorological forces and return to the earth's surface be thoroughly understood. Only a beginning to develop such an organized set of scientific data has been made.

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Measurement of Fallout

It has been the overall objective of the fallout measurements made by N at the Nevada test site (3, 9, 12) and the Eniwetok Proving Grounds (1, 5 to obtain those data which would allow prediction techniques to be tested assessment methods developed for the radiological situations resulting fro wide range of nuclear detonation conditions (8).

Since fallout predictions result in the construction of gamma intensity tours, one group of measurements has featured the collection of experim data for such contours. Direct measurement of the gamma ionization rat a large number of points in the fallout area with a hand survey meter is simplest and in many ways the most satisfactory method of obtaining this of information (2, 4). When the fallout has been deposited on a solid surfa as in Nevada, surveys of this type have generally been used and further sup mented with measurements on instruments calibrated in terms of ionizatio the activities of samples collected at certain locations for the primary purp of physical, chemical, and radiochemical studies. When the fallout has bee deposited on a water surface, as in the Pacific, certain other measurements required for the interpretation of survey results. Because of the way in whi the fallout material settles and disperses in the water, it has been necessary measure its distribution to the total depth of mixing at each point of measure ment before the total fallout deposited at that point could be computed. Th has been accomplished in part by the use of a radiation sensitive probe whic could be lowered to various depths, and in part by measuring the activities of samples collected at various depths. Both procedures have required critical in strument calibrations and theoretical work involving a number of assumption however, and it is probable that the results are much less accurate than those for the land surface case. In general, the measurements of this kind made by NRDL have shown that areas of the order of tens of square miles are subjected at early times to ionization intensities greater than 5 r/hr. by events in the low KT range and areas of the order of thousands of square miles to ionization inten sities greater than 5 r/hr. by events in the MT range. Levels of several thousand

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ASUREMENT OF FALLOUT

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disperses in the water, it has been necessary
total depth of mixing at each point of measur
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the order of tens of square miles are subjected
isities greater than 5 r/hr. by events in the
of thousands of square miles to ionization inte
ts in the MT range. Levels of several thousand

r/hr. at early times for both yield ranges have been measured or inferred, although less than 10 percent of the total affected area was estimated to have experienced these levels. While the probable error for contours from survey ionization rate measurements has been estimated ±20 percent for Nevada KT events, corresponding land equivalent contours for MT events in the Pacific cannot be estimated closer than within a factor of 2 or 3 at the present time.

Another group of measurements has ben directed toward obtaining time dependent data, such as the variation of the gamma field intensity and gamma energy spectrum with time and the distribution of particle sizes deposited with time at a number of locations in the fallout area (10, 12). Such information is needed both to check model theory which yields similar results and to provide a complete description of fallout phenomena. The changing gama radiation field has usually been measured by means of an instrument which recorded increments of ionization dose received at its location from all sources within unit time intervals, while gamma energy spectra have been measured on fallout samples from a known fallout area with an instrument utilizing a crystal detector, a photomultiplier and a pulse height discriminator (7, 12). NRDL results have shown that the gamma radiation field due to fallout outside the area of severe blast damage tends to build up to a maximum in approximately twice the time required for the fallout to arrive, varying from a few minutes near ground zero to 24 hours or more at distances of over 100 miles. The radioactive decay of fission products may be approximately by a straight line of slope—1.2 on a log log plot; however the more general case in which several induced activities are present, and the fission products are fractionated, leads to a complex decay curve. Spectral measurements show the average energy of the fallout gamma radiations to vary from about 0.6 Mev. at 10 hr. to 0.3 Mev. at 300 hr.

The determination of particle size distributions with time has required the development and application of specialized collectors capable of sampling automatically over consecutive time intervals from a few minutes to an hour or more, as well as special methods and instruments for sizing and counting the collected particles. It has been found that particles with diameters between 50 and 300 microns predominate in most collections with larger sizes (2,000-1,000 microns) increasing nearer ground zero and smaller sizes (20-100 microns) increasing farther away from ground zero. In general, data of this kind, being more direct, are more reliable for computing fraction of the bomb in the total fallout than survey results—although several sources of error such as sample bias 11 and radionuclide fractionation, do exist. On the scale utilized above, standard error in fraction calculations might be estimated at about ±25 percent for the gamma energy and emission rate method, as opposed to possibly several hundred percent by the survey method for water surfaces and less than 100 percent for land surfaces.

Extensive physical, chemical, and radiochemical analyses have been performed on the particulate produced by detonations occurring on the sandy Nevada soil and on coral atolls and the ocean surface in the Pacific. The mass of such material as well as the fraction of the bomb deposited per unit area at a number of locations has also been determined by weighing collected samples and performing radiochemical analyses. Since fallout ingestion constitutes a separate hazard from exposure to external fallout radiation, and since countermeasures and recovery procedures depend heavily on knowledge of the various properties of the contaminant, information of this kind is essential for assessment purposes.

NRDL has consistently emphasized measurements of local fallout and characterization of the phenomena associated with it. It has been possible, nevertheless, to estimate the fraction available for worldwide fallout by subtraction of the local fallout from the total produced, and this has been found to be something of the order of 50 percent for both land surface and water surface events. No closer estimate can be given because of the many uncertainties and sources of possible error in the measurements and calculations.

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Environmental Aerosol Analysis

The United States Naval Radiological Defense Laboratory (USNRDL) collects and analyzes daily aerosol samples for airborne activity of air passing over the laboratory. Twenty-four-hour air samples have been collected and analyzed daily since January 1950, and is a continuing program at the laboratory. The attached graphs present a summary of the long-lived activity and half-life for these daily aerosol samples. Additional analysis on representative aerosol samples indicated this activity is due to airborne beta-gamma fission products. The appropriate dates of the various United States nuclear weapon tests are indicated.

It is observed from the graphs that in 1950 there was essentially no fission product activity in excess of 10^{-14} μc/cc. In 1951, the aerosol activity rose during the Ranger and Greenhouse operations but then dropped back to an average of 3×10^{-14} μc/cc. Successive rises and falls of the aerosol activity are noted for the succeeding years. The rises in aerosol activity, fall of 1951, 1953, 1954, 1955, and 1956 were not produced by the United States or United Kingdom nuclear weapon tests. Since December 1955, the aerosol activity has varied between 10^{-13} and 10^{-12} μc/cc. In other words, the fission product activity background was less than 10^{-14} μc/cc in 1950, but is now around 5×10^{-13} μc/cc. The present concentration of airborne fission products is at most one-tenth of the natural radiactive aerosol (radon and thoron) concentration and is one-fifty thousandth of the industrial maximum permissible concentration for continuous exposure to undetermined mixtures of beta-gamma emitters.

Naval Radiological Defense Laboratory. USNRDL-TR-127. A FALLOUT PLOTTING DEVICE, by E. A. Schuert. 30 Nov. 1956. 19 p. illus. UNCLASSIFIED A fallout plotting device was developed. The method requires no drafting equipment and is ideally suited for field use. At Operation REDWING it was found that untrained personnel could quickly become proficient in its employment.	1. Fallout - Course mapping 2. Plotters I. Schuert, E. A. II. Title. III. NS 081-001. UNCLASSIFIED

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A Fallout Forecasting Technique With Results Obtained at the Eniwetok Proving Ground [Draft]

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ADMINISTRATIVE INFORMATION

The work described herein is a part of the research sponsored by BuShips and the United States Army and locally designated as program 2, problem 3, phase 1. Its technical objective is AW-7 and it is described on RDB card NS 081-001.

SUMMARY

The problem: A fallout forecasting technique is needed to qualitatively describe the fallout hazard resulting from nuclear detonations. This technique should have such flexibility that its employment is valid for field use.

Findings: A summary of the latest experimental and theoretical considerations has resulted in the development of a technique whose complexity is dependent on the required accuracy of the results desired. This technique has been satisfactorily tested at the Eniwetok Proving Grounds for land surface and water surface bursts.

ABSTRACT

A generalized fallout forecasting technique is presented with detailed computations of input parameters for use in the Marshal Islands.

Results obtained at a recent weapons test are briefly discussed by comparison of forecast fallout with preliminary measured data.

1. INTRODUCTION

Fallout research continues to seek a theoretical working model that will describe in detail the mechanism of fallout. Aside from this long-range problem, consideration must be given to making available a working tool that will meet the needs of the military for solving fallout problems in the field. Such consideration requires a simplified rapid system capable of producing qualitative if not quantitative results.

Within a program studying fallout at a recent weapons test operation there was a fallout forecasting assignment that had many aspects of the practical

11.2 Activity distribution in source model

The great part of the activity was assumed to be concentrated in the lower third of the mushroom. The lower two-thirds of the stem was ignored; the remainder of the stem and upper two-thirds of the cloud were weighted lightly. This description (fig. 3) of the activity distribution within the cloud appeared most reasonable in the light of available data and logical theoretical considerations. The activity was concentrated nearer the axis of symmetry of the cloud than at its outer edges.

11.3 Particle size distribution in source model

All particle sizes were assumed at all elevations within the cloud except the lower two-thirds of the stem. However, to obtain agreement with past fallout measurements and with the optical diameter of the mushroom, it was necessary to fractionate the particle size distribution radially within the cloud. Otherwise, the computed fallout area about ground zero would be too large. The fractionation was specified as follows: particles of 1,000 microns in diameter and larger were restricted to the inner 10 percent of the mushroom radius or approximately the stem radius; those from 500 to 1,000 microns in diameter were limited to the inner 50 percent of the cloud radius. Since the relation of activity to particle size is some function of the particle diameter this fractionation tends to concentrate the activity about the axis of symmetry of the cloud.

11.4 Particle falling speeds or settling rates

Computations of the terminal velocities of the particles were based on aerodynamic considerations for a still atmosphere having temperature and density distributions typical of the Marshall Islands atmosphere in the spring months.

Experimental data from past tests at Eniwetok Atoll indicated that the particles were irregular in shape and had a mean density of 2.36 g/cu cm.

It can be shown that particles falling at their terminal speed experience three types of flow in a fluid: streamline or laminar flow where viscous forces predominate, ($10^{-4} \leq R_e \leq 2.0$); intermediate flow where inertia forces predominate, ($2 \leq R_e \leq 500$); turbulent flow where inertia forces predominate, ($500 \leq R_e \leq 10^5$). Below a Reynolds number of 10^{-4} certain corrections must be applied to the equations because the particle diameter approaches the mean free path of the fluid medium; the region above a Reynolds number of 10^5 is important only in ballistics. These limiting cases will not be discussed here.

The parameters actively affecting a particle's falling speed are: its weight, its drag coefficient, its density, as well as the fluid density and fluid viscosity.

Most empirical equations developed in past experimental work have been for spheres dropped in various liquids. Some work has been done on irregular shaped particles and some done in wind tunnels. The equations[1] used to determine the falling rates for particles in a fluid medium follow.

For Streamline motion, $10^{-4} \leq R_e \leq 2.0$

$$V_s = K_s \left(\frac{\rho - \rho_o}{\rho_o}\right) (d^2) \left(\frac{\mu}{\rho_o}\right)^{-1} \tag*{(1)[2]}$$

where

V_s = terminal velocity in cm/sec
ρ = particle density in gms/cm³
ρ_o = fluid density in gms/cm³
d = particle diameter in cm
μ = absolute viscosity of fluid in poises
K_s = constant incorporating gravity
= 54.5 for spheres
= 36.0 for irregular shaped particles.

The limiting diameter to which Eq. 1 holds is

$$d' = \left(\frac{36\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for spheres and

$$d' = \left(\frac{54.4\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for irregular shaped particles.

[1] J. M. Dallavalle, Mircomeritics, Pittman Publishing Corp., 1948.

For Intermediate motion, $2.0 \leqq R_e \leqq 500$

$$V_I = K_I \left(\frac{\rho - \rho_o}{\rho_o}\right)^{2/3} \left(\frac{\mu}{\rho_o}\right)^{-1/3} d_o$$

where $d_o = d - \xi d'$
$\xi = 0.4$ for spheres
$\xi = 0.279$ for irregular shapes
d' = limiting diameter to which streamline motion applies
$K_I = 30.0$ for spheres
$= 19.0$ for irregular shapes.

The limiting diameter to which the Eq. 2 holds is

$$d'' = 43.5 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for spheres

$$d'' = 51 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for irregular shapes.

For Turbulent motion, $500 \leqq R_e \leqq 10^5$

$$V_T = K_T \left[\left(\frac{\rho - \rho_o}{\rho_o}\right) d\right]^{1/2}$$

$K_T = 54.6$ for spheres
$= 50.0$ for irregular particles.

The question of particle diameter becomes puzzling when the equation[s are] applied to irregular shaped particles. Although the equations for irregular sh[aped] particles cannot be applied to an individual particle, they are assumed val[id in] establishing the average falling rates of many irregular particles clustered [about] this defined size.

2.1.5 *Marshall Islands atmosphere*

Marshall Islands atmospheric conditions determined the values for the de[nsity] and viscosity parameters used in computing particle falling rates. Avail[able] data on the temperature, pressure, density, and viscosity as functions of alti[tude] for the atmosphere common to the Marshall Island area in the spring mo[nths] follow.

It was not possible to use a "standard atmosphere" in this problem bec[ause] such use introduced a large error in the particle falling rate at high altitu[des.] This error originates primarily because of the assumed isothermal layer ab[ove] the tropopause.

2.1.5.1 *Temperature distribution*

From the weather data published by Task Force Weather Central at Operat[ion] Castle, four published radiosonde runs obtained temperature measurement[s at] high altitudes:

March 1, 1954, 0600 M Bikini
March 27, 1954, 0600 M Bikini
April 7, 1954, 0620 M Bikini
April 26, 1954, 0610 M Bikini

No data were available above 67,000 feet. Fortunately two of these [runs] penetrated the tropopause which was located at approximately 55,000 feet. [To] extend the measured data beyond 67,000 feet climatological averages [3] for lati[tude] 12° North were employed. Agreement with measured data was satisfac[tory] except for the range from 50,000 to 65,000 feet where the climatological [data] indicated a well-defined isothermal layer. The most significant finding from [the] measured data was the complete lack of an isothermal layer above the tropop[ause.] Instead, a distinct and rapid inversion was observed which when extrapolate[d as] a straight line agreed with the climatological data above 70,000 feet. Since [the] atmosphere was to be defined to 120,000 feet further extrapolation was neces[sary.] The only temperature data available at these higher altitudes were take[n by] rockets [4] over White Sands, N. Mex. A plot of 3 points from the rocket [data] justifies to some extent a continued extrapolation of the curve to 120,000 feet.

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[2] These equations were taken from reference 1; however, certain constants have been reevaluated.
[3] Brunt, David, Physical and Dynamical Meteorology, the University Press, 1941.
[4] Chief of Naval Operations, A Study of the Atmosphere Between 30,000 and 10[0,000] Feet (preliminary report), September 1948.

Therefore the profile of the vertical temperature gradient (fig. 4) was based on measured data to 67,000 feet and extrapolated to 120,000 feet on the basis of supporting climatological data and temperature measurements made at high altitudes with rockets.

1.5.2 *Pressure distribution*

Published high altitude measurements of the pressure distribution were obtained on two occasions at Operation Castle. These measurements[4] were made at Bikini on April 7 and 26, 1954, and were not taken above 65,000 feet. Above this altitude the pressure was extrapolated as a straight line on semilog paper to 120,000 feet. Agreement with published rocket data from White Sands, N. Mex., was good to 90,000 feet (fig. 5).

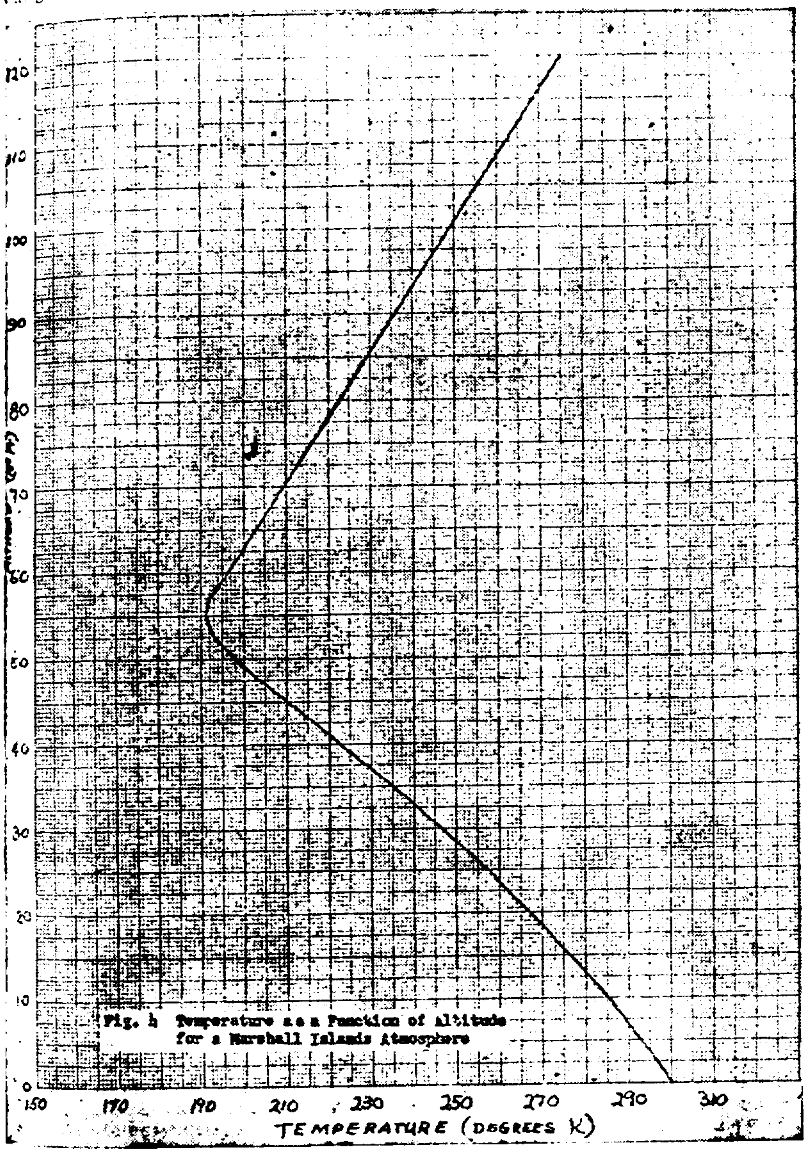

Fig. 4 Temperature as a Function of Altitude for a Marshall Islands Atmosphere

[4] Hq. T. U.-13 operation memo No. 14, April 3, 1954.

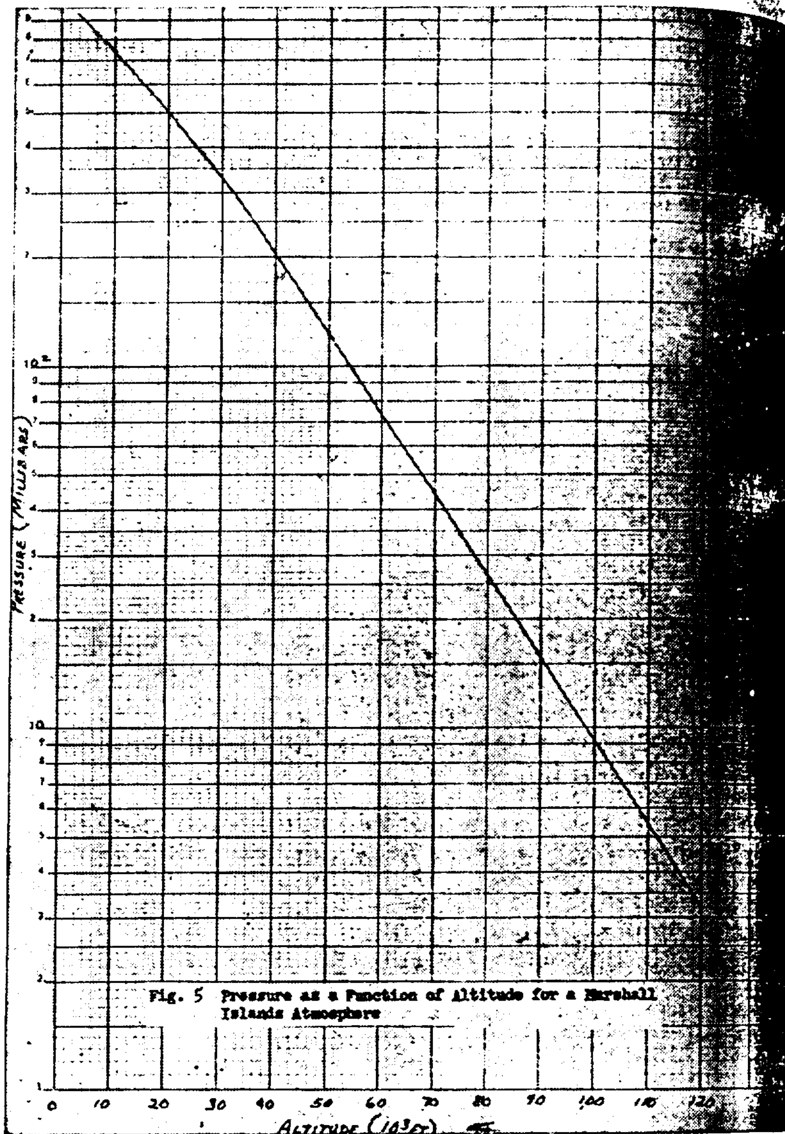

Fig. 5 Pressure as a Function of Altitude for a Marshall Islands Atmosphere

2.1.5.3 Density distribution

The density distribution of the atmosphere (fig. 6) was calculated from the perfect gas law using the above pressure and temperature distributions,

$$\rho = \frac{P}{RT}$$

where the gas constant was taken for dry air. This assumption of no moisture in the mixture introduces an error of several percent in the lower layers of the atmosphere where the relative humidity is high; however, it can be safely neglected. As well, the latest theories on the composition of the atmosphere indicate it to be constant to altitudes above 150,000 feet which justified the assumption of a non-varying gas constant.

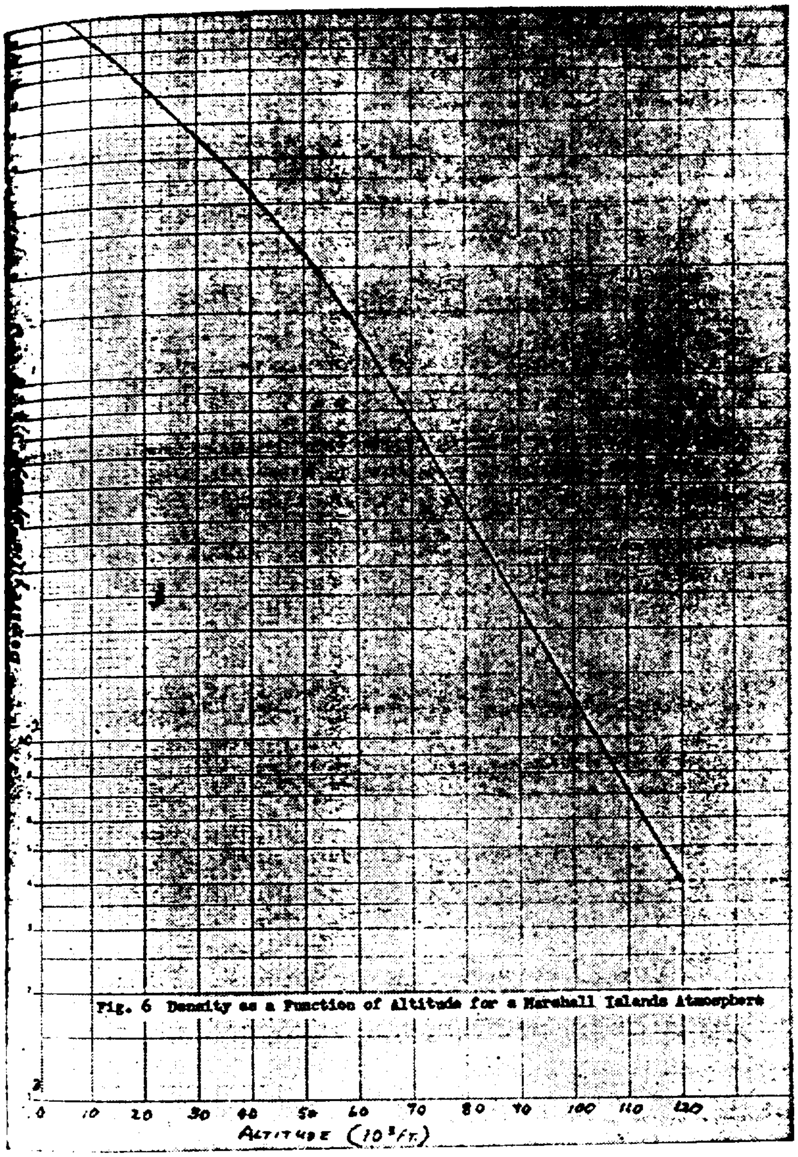

Fig. 6 Density as a Function of Altitude for a Marshall Islands Atmosphere

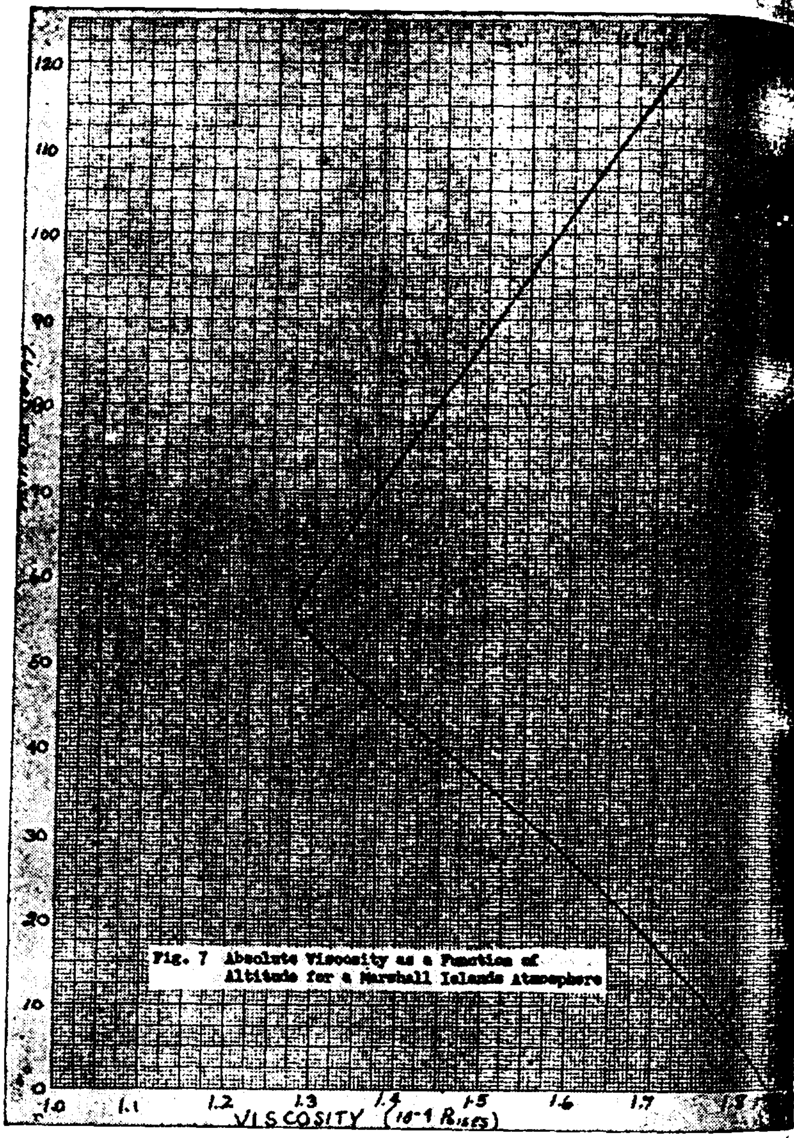

Fig. 7 Absolute Viscosity as a Function of Altitude for a Marshall Islands Atmosphere

11.5.4 Viscosity distribution

The variation of absolute viscosity with altitude was computed from the observed temperature distribution using Sutherland's formula,[6]

$$\mu = u_o \left(\frac{T_0+114}{T+114}\right)\left(\frac{T}{T_o}\right)^{1/2}$$

$$u = 0.01709 \left(\frac{387.17}{t_i+114}\right)\left(\frac{t_i}{273.17}\right)^{1/2}$$

where t_i equals temperature in degrees Kelvin and μ is viscosity in centipoises. These data are plotted in figure 7.

The data on pressure, temperature, density, and viscosity in 1,000-foot intervals to 120,000 feet are summarized in table 1.[7]

TABLE 1.—*Table of temperature, pressure, density, and viscocity of the atmosphere over the Marshall Islands during the spring*

Altitude (feet)	Temperature ° K	Pressure (Mb)	Density (g/cm³·10³)	Viscosity (poises·10⁴)
SFC	300	1,006	1.17	1.84
1,000	299	980	1.13	1.83
2,000	297	950	1.10	1.825
3,000	296	930	1.06	1.815
4,000	295	900	1.03	1.810
5,000	293	870	1.0	1.805
6,000	292	850	.97	1.795
7,000	290	820	.94	1.785
8,000	289	800	.91	1.780
9,000	288	770	.88	1.770
10,000	285	740	.86	1.765
11,000	284	720	.83	1.775
12,000	282	690	.80	1.745
13,000	280	660	.78	1.740
14,000	278	640	.76	1.730
15,000	276	620	.73	1.720
16,000	274	590	.71	1.715
17,000	273	570	.69	1.705
18,000	271	550	.67	1.695
19,000	269	530	.65	1.685
20,000	267	500	.63	1.675
21,000	265	480	.61	1.665
22,000	263	460	.59	1.655
23,000	261	440	.57	1.645
24,000	259	420	.55	1.635
25,000	257	410	.53	1.625
26,000	255	390	.52	1.615
27,000	252	370	.50	1.600
28,000	250	355	.49	1.590
29,000	248	340	.47	1.580
30,000	246	320	.45	1.570
31,000	243	310	.43	1.560
32,000	241	300	.42	1.545
33,000	239	280	.41	1.535
34,000	236	270	.39	1.525
35,000	234	260	.38	1.510
36,000	232	245	.37	1.500
37,000	230	235	.36	1.490
38,000	227	225	.35	1.475
39,000	225	215	.33	1.465
40,000	223	205	.32	1.450
41,000	220	195	.31	1.440
42,000	218	185	.30	1.430
43,000	215	175	.29	1.420
44,000	213	165	.28	1.405
45,000	211	160	.27	1.395
46,000	209	150	.26	1.380
47,000	206	145	.25	1.370
48,000	204	135	.24	1.355
49,000	201	130	.23	1.345
50,000	199	125	.22	1.335
51,000	196	115	.21	1.320
52,000	194	110	.20	1.310
53,000	193	105	.19	1.295
54,000	192	100	.18	1.285

[6] Smithsonian Physical Tables, 1954.

[7] A great deal of excellent upper air data for the Marshall Islands was obtained at Operation Redwing in 1956. Reduction of these data will result in a much better description of the Marshall Islands atmosphere than has been previously available.

TABLE 1.—*Table of temperature, pressure, density, and viscosity of the atmosphere over the Marshall Islands during the spring*—Continued

Altitude (feet)	Temperature ° K	Pressure (Mb)	Density (g/cm³·10³)	Viscosity (poises·10⁴)
55,000	191	95	.17	[illegible]
56,000	191	90	.16	[illegible]
57,000	192	85	.155	[illegible]
58,000	193	80	.145	[illegible]
59,000	194	77	.14	[illegible]
60,000	195	73	.135	[illegible]
61,000	197	70	.125	[illegible]
62,000	198	66	.115	[illegible]
63,000	199	63	.110	[illegible]
64,000	201	60	.105	[illegible]
65,000	202	56	.10	[illegible]
66,000	203	53	.094	[illegible]
67,000	205	50	.088	[illegible]
68,000	206	48	.083	[illegible]
69,000	207	46	.078	[illegible]
70,000	208	43	.073	[illegible]
71,000	210	41	.070	[illegible]
72,000	211	39	.066	[illegible]
73,000	213	37	.062	[illegible]
74,000	214	35	.058	[illegible]
75,000	215	33	.054	[illegible]
76,000	217	32	.052	[illegible]
77,000	218	30	.049	[illegible]
78,000	219	28	.046	[illegible]
79,000	221	27	.044	[illegible]
80,000	222	26	.042	[illegible]
81,000	223	24	.039	[illegible]
82,000	225	23	.037	[illegible]
83,000	226	22	.034	[illegible]
84,000	227	21	.032	[illegible]
85,000	229	20	.030	[illegible]
86,000	230	19	.029	[illegible]
87,000	231	18	.027	[illegible]
88,000	233	17	.026	[illegible]
89,000	234	16	.024	[illegible]
90,000	235	15	.023	1.510
91,000	237	14.5	.0215	1.520
92,000	238	14	.0205	1.525
93,000	239	13	.019	[illegible]
94,000	241	12.5	.018	1.540
95,000	242	12	.017	1.550
96,000	243	11	.016	1.555
97,000	245	10.5	.015	1.565
98,000	246	10	.014	1.570
99,000	247	9.5	.0135	1.575
100,000	249	9	.0130	1.585
101,000	250	8.5	.0102	1.590
102,000	251	8	.01015	1.600
103,000	253	7.6	.0105	1.605
104,000	254	7.4	.010	1.610
105,000	255	7.0	.0095	1.620
106,000	257	6.6	.0090	1.625
107,000	258	6.2	.0085	1.635
108,000	259	6.0	.0080	1.640
109,000	261	5.6	.0075	1.650
110,000	262	5.4	.0070	1.655
111,000	263	5.1	.0068	1.660
112,000	265	4.9	.0064	1.670
113,000	266	4.6	.0060	1.675
114,000	267	4.4	.0056	1.685
115,000	269	4.2	.0054	1.690
116,000	270	3.9	.0050	1.700
117,000	271	3.7	.0048	1.705
118,000	273	3.6	.0044	1.710
119,000	274	3.4	.0042	1.720
120,000	275	3.2	.0040	1.725

2.1.5.5 *Terminal velocity computations*

The average falling speed through 5,000-foot layers was computed for 4 particle sizes over an altitude range from 0 to 120,000 feet. In these computations all in-flight transition of the particles from streamline to intermediate flow had to be considered through use of the plot shown in figure 8.

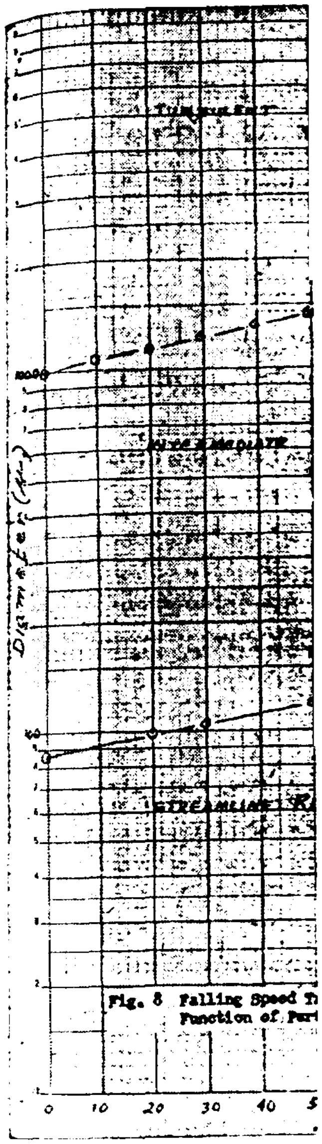

Fig. 8 Falling Speed T
Function of Part

Four particle sizes (75 μ, 10
since there was evidence from p
distance of fallout of interest
within this limit. Table 2 pres
Tables 3, 4, 5, and 6 display th
for these particle diameters.

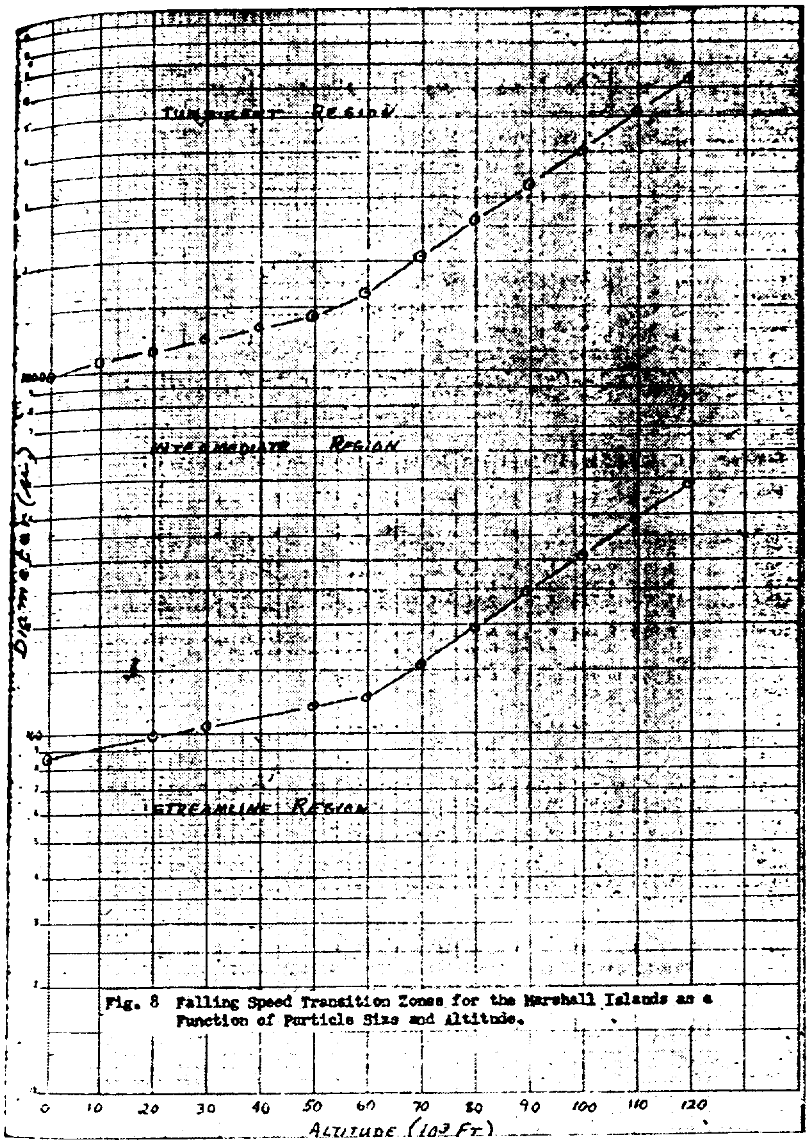

Fig. 8 Falling Speed Transition Zones for the Marshall Islands as a Function of Particle Size and Altitude.

Four particle sizes (75 μ, 100 μ, 200 μ, and 350 μ diameter) were employed since there was evidence from past tests that the 75 μ particle defined the limiting distance of fallout of interest and the larger sizes best described the pattern within this limit. Table 2 presents the falling speeds computed for the 4 sizes. Tables 3, 4, 5, and 6 display the cumulative time of fall from a given altitude for these particle diameters.

TABLE 2.—*Falling speeds as a function of altitude*

[Falling speeds (foot-hour)]

Altitude	75	100	200	350	Altitude	75	100	200
0	3,060	5,040	11,700	21,600	65	4,190	7,480	26,100
5	3,120	5,240	12,300	22,900	70	4,110	7,320	27,600
10	3,200	5,480	12,900	24,100	75	4,010	7,150	28,100
15	3,270	5,750	13,700	25,500	80	3,910	6,960	27,800
20	3,360	5,980	14,400	27,100	85	3,800	6,770	27,100
25	3,470	6,160	15,300	28,800	90	3,720	6,640	26,500
30	3,570	6,380	16,300	30,800	95	3,620	6,470	25,800
35	3,720	6,640	17,500	33,000	100	3,550	6,340	25,300
40	3,870	6,910	18,600	35,300	105	3,470	6,180	24,800
45	4,040	7,200	19,800	37,800	110	3,400	6,050	24,000
50	4,210	7,520	21,400	40,600	115	3,330	5,930	23,700
55	4,420	7,860	23,200	44,600	120	3,260	5,800	23,400
60	4,200	7,700	24,400	47,200				

TABLE 3.—*Cumulative time of fall for the 75-μ particles*

[Cumulative time of fall (hours)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	[illegible]
120 to 115	1.52											
115 to 110	3.01	1.49										
110 to 105	4.46	2.94	1.45									
105 to 100	5.88	4.36	2.87	1.42								
100 to 95	7.27	5.75	4.26	2.81	1.39							
95 to 90	8.63	7.11	5.62	4.17	2.75	1.36						
90 to 85	9.96	8.44	6.95	5.50	4.08	2.69	1.33					
85 to 80	11.26	9.74	8.25	6.80	5.38	3.99	2.63	1.30				
80 to 75	12.52	11.00	9.61	8.06	6.64	5.25	3.89	2.56	1.26			
75 to 70	13.75	12.23	10.74	9.29	7.87	6.48	5.12	3.79	2.49	1.23		
70 to 65	14.95	13.43	11.94	10.49	9.07	7.68	6.32	4.99	3.69	2.43	1.20	
65 to 60	16.14	14.62	13.13	11.68	10.26	8.87	7.51	6.18	4.88	3.62	2.39	[illegible]
60 to 55	17.30	15.78	14.29	12.84	11.42	10.03	8.67	7.34	6.04	4.78	3.55	[illegible]
55 to 50	18.46	16.94	15.45	14.00	12.58	11.19	9.83	8.50	7.20	5.94	4.71	[illegible]
50 to 45	19.67	18.15	16.66	15.21	13.79	12.40	11.04	9.71	8.41	7.15	5.92	[illegible]
45 to 40	20.93	19.41	17.92	16.47	15.05	13.66	12.30	10.97	9.67	8.41	7.18	[illegible]
40 to 35	22.25	20.73	19.24	17.79	16.37	14.98	13.62	12.29	10.99	9.73	8.50	[illegible]
35 to 30	23.62	22.10	20.61	19.16	17.74	16.35	14.99	13.66	12.36	11.10	9.87	[illegible]
30 to 25	25.04	23.52	22.03	20.58	19.16	17.77	16.41	15.08	13.78	12.52	11.29	[illegible]
25 to 20	26.50	24.98	23.49	22.04	20.62	19.23	17.87	16.54	15.24	13.98	12.75	[illegible]
20 to 15	28.01	26.49	25.00	23.55	22.13	20.74	19.38	18.05	16.75	15.49	14.26	[illegible]
15 to 10	29.55	28.03	26.54	25.09	23.67	22.28	20.92	19.59	18.29	17.03	15.80	[illegible]
10 to 5	31.13	29.61	28.12	26.67	25.25	23.86	22.50	21.17	19.87	18.61	17.38	[illegible]
5 to 0	32.75	31.23	29.74	28.29	26.87	25.48	24.12	22.79	21.49	20.23	19.00	[illegible]

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115												
115 to 110												
110 to 105												
105 to 100												
100 to 95												
95 to 90												
90 to 85												
85 to 80												
80 to 75												
75 to 70												
70 to 65												
65 to 60												
60 to 55	1.16											
55 to 50	2.32	1.16										
50 to 45	3.53	2.37	1.21									
45 to 40	4.79	3.63	2.47	1.26								
40 to 35	6.11	4.95	3.79	2.58	1.32							
35 to 30	7.48	6.32	5.16	3.95	2.69	1.37						
30 to 25	8.90	7.74	6.58	5.37	4.11	2.79	1.42					
25 to 20	10.36	9.20	8.04	6.83	5.57	4.25	2.88	1.46				
20 to 15	11.87	10.71	9.55	8.34	7.08	5.76	4.39	2.97	1.51			
15 to 10	13.41	12.25	11.09	9.88	8.62	7.30	5.93	4.51	3.05	1.54		
10 to 5	14.99	13.83	12.67	11.46	10.20	8.88	7.51	6.09	4.63	3.12	1.58	
5 to 0	16.61	15.45	14.29	13.08	11.82	10.52	9.13	7.71	6.25	4.74	3.20	[illegible]

TABLE 4.—*Cumulative time of fall for the 100-μ particles*

[Cumulative time of fall (hour)]

Starting elevation (feet 10^{-3})	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	0.85	------	------	------	------	------	------	------	------	------	------	------
120 to 110	1.68	0.83	------	------	------	------	------	------	------	------	------	------
120 to 105	2.50	1.65	0.82	------	------	------	------	------	------	------	------	------
120 to 100	3.30	2.45	1.62	0.80	------	------	------	------	------	------	------	------
120 to 95	4.08	3.22	2.40	1.58	0.78	------	------	------	------	------	------	------
120 to 90	4.84	3.99	3.16	2.34	1.54	0.76	------	------	------	------	------	------
120 to 85	5.58	4.73	3.90	3.08	2.28	1.50	0.74	------	------	------	------	------
120 to 80	6.30	5.46	4.63	3.81	3.01	2.23	1.47	0.73	------	------	------	------
120 to 75	7.02	6.17	5.34	4.52	3.72	2.94	2.18	1.44	0.71	------	------	------
120 to 70	7.71	6.86	6.03	5.21	4.41	3.63	2.87	2.13	1.40	0.69	------	------
120 to 65	8.38	7.53	6.70	5.88	5.05	4.30	3.54	2.80	2.07	1.36	0.67	------
120 to 60	9.04	8.19	7.36	6.54	5.74	4.96	4.20	3.46	2.73	2.02	1.33	0.66
120 to 55	9.68	8.83	8.00	7.18	6.38	5.60	4.84	4.10	3.37	2.66	1.97	1.30
120 to 50	10.33	9.48	8.65	7.83	7.03	6.25	5.49	4.75	4.02	3.31	2.62	1.95
120 to 45	11.01	10.16	9.33	8.51	7.71	6.93	6.17	5.43	4.70	3.99	3.30	2.63
120 to 40	11.72	10.87	10.04	9.22	8.42	7.64	6.88	6.14	5.41	4.70	4.01	3.34
120 to 35	12.46	11.61	10.78	9.96	9.16	8.38	7.62	6.88	6.15	5.44	4.75	4.08
120 to 30	13.24	12.39	11.56	10.74	9.94	9.16	8.40	7.66	6.93	6.22	5.53	4.86
120 to 25	14.03	13.18	12.35	11.53	10.73	9.95	9.19	8.45	7.72	7.01	6.32	5.65
120 to 20	14.85	14.00	13.17	12.35	11.55	10.77	10.01	9.27	8.54	7.83	7.14	6.47
120 to 15	15.70	14.85	14.02	13.20	12.40	11.62	10.86	10.12	9.39	8.68	7.99	7.32
120 to 10	16.56	15.74	14.91	14.09	13.29	12.51	11.75	11.01	10.28	9.57	8.88	8.21
120 to 5	17.52	16.67	15.84	15.02	14.22	13.44	12.68	11.94	11.21	10.50	9.81	9.14
120 to 0	18.49	17.64	16.81	15.99	15.19	14.41	13.65	12.91	12.18	11.47	10.78	10.11

Starting elevation (feet 10^{-3})	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115	------	------	------	------	------	------	------	------	------	------	------	------
120 to 110	------	------	------	------	------	------	------	------	------	------	------	------
120 to 105	------	------	------	------	------	------	------	------	------	------	------	------
120 to 100	------	------	------	------	------	------	------	------	------	------	------	------
120 to 95	------	------	------	------	------	------	------	------	------	------	------	------
120 to 90	------	------	------	------	------	------	------	------	------	------	------	------
120 to 85	------	------	------	------	------	------	------	------	------	------	------	------
120 to 80	------	------	------	------	------	------	------	------	------	------	------	------
120 to 75	------	------	------	------	------	------	------	------	------	------	------	------
120 to 70	------	------	------	------	------	------	------	------	------	------	------	------
120 to 65	------	------	------	------	------	------	------	------	------	------	------	------
120 to 60	------	------	------	------	------	------	------	------	------	------	------	------
120 to 55	0.64	------	------	------	------	------	------	------	------	------	------	------
120 to 50	1.29	0.67	------	------	------	------	------	------	------	------	------	------
120 to 45	1.97	1.35	0.68	------	------	------	------	------	------	------	------	------
120 to 40	2.68	2.04	1.39	0.71	------	------	------	------	------	------	------	------
120 to 35	3.42	2.78	2.13	1.45	0.74	------	------	------	------	------	------	------
120 to 30	4.20	3.56	2.91	2.23	1.52	0.78	------	------	------	------	------	------
120 to 25	4.99	4.35	3.70	3.02	2.31	1.57	0.79	------	------	------	------	------
120 to 20	5.81	5.17	4.52	3.84	3.13	2.39	1.61	0.82	------	------	------	------
120 to 15	6.66	6.02	5.37	4.69	3.98	3.14	2.46	1.67	0.85	------	------	------
120 to 10	7.55	6.91	6.26	5.58	4.87	4.13	3.35	2.56	1.74	0.89	------	------
120 to 5	8.48	7.84	7.19	6.51	5.80	5.06	4.28	3.49	2.67	1.82	0.93	------
120 to 0	9.45	8.81	8.16	7.48	6.77	6.03	5.25	4.46	3.64	2.79	1.90	0.97

TABLE 5.—*Cumulative time of fall for 200-μ particles*

[Cumulative time of fall (hour)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	0.21											
115 to 110	.42	0.21										
110 to 105	.62	.41	0.20									
105 to 100	.82	.61	.40	0.20								
100 to 95	1.02	.81	.60	.40	0.20							
95 to 90	1.21	1.00	.79	.59	.39	0.19						
90 to 85	1.40	1.19	.98	.78	.58	.38	0.19					
85 to 80	1.58	1.37	1.16	.96	.76	.56	.37	0.18				
80 to 75	1.76	1.55	1.34	1.14	.94	.74	.55	.36	0.18			
75 to 70	1.94	1.73	1.52	1.32	1.12	.92	.73	.54	.36	0.18		
70 to 65	2.13	1.92	1.71	1.51	1.31	1.11	.92	.73	.55	.37	0.19	
65 to 60	2.33	2.12	1.91	1.71	1.51	1.31	1.12	.93	.75	.57	.39	
60 to 55	2.54	2.33	2.12	1.92	1.72	1.52	1.33	1.14	.96	.78	.60	[illegible]
55 to 50	2.76	2.55	2.34	2.14	1.94	1.74	1.55	1.36	1.18	1.00	.82	[illegible]
50 to 45	3.00	2.79	2.58	2.38	2.18	1.98	1.79	1.60	1.42	1.24	1.06	[illegible]
45 to 40	3.26	3.05	2.84	2.64	2.44	2.24	2.05	1.86	1.68	1.50	1.32	[illegible]
40 to 35	3.54	3.33	3.12	2.92	2.72	2.52	2.33	2.14	1.96	1.78	1.60	[illegible]
35 to 30	3.84	3.63	3.42	3.22	3.02	2.82	2.63	2.44	2.26	2.08	1.90	[illegible]
30 to 25	4.16	3.95	3.74	3.54	3.34	3.14	2.95	2.76	2.58	2.40	2.22	[illegible]
25 to 20	4.50	4.29	4.08	3.88	3.68	3.48	3.29	3.10	2.92	2.74	2.56	[illegible]
20 to 15	4.86	4.65	4.44	4.24	4.04	3.84	3.65	3.46	3.28	3.10	2.92	[illegible]
15 to 10	5.24	5.03	4.82	4.62	4.42	4.22	4.03	3.84	3.66	3.48	3.30	[illegible]
10 to 5	5.64	5.43	5.22	5.02	4.82	4.62	4.43	4.24	4.06	3.88	3.70	[illegible]
5 to 0	6.06	5.85	5.64	5.44	5.24	5.04	4.85	4.66	4.48	4.30	4.12	[illegible]

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115												
115 to 110												
110 to 105												
105 to 100												
100 to 95												
95 to 90												
90 to 85												
85 to 80												
80 to 75												
75 to 70												
70 to 65												
65 to 60												
60 to 55	0.21											
55 to 50	.43	0.22										
50 to 45	.67	.46	0.24									
45 to 40	.93	.72	.50	0.26								
40 to 35	1.21	1.00	.78	.54	0.28							
35 to 30	1.51	1.30	1.08	.84	.58	0.30						
30 to 25	1.83	1.62	1.40	1.16	.90	.62	0.32					
25 to 20	2.17	1.96	1.74	1.50	1.24	.96	.66	0.34				
20 to 15	2.53	2.32	2.10	1.86	1.60	1.32	1.02	.70	0.36			
15 to 10	2.91	2.70	2.48	2.24	1.98	1.70	1.40	1.08	.74	0.38		
10 to 5	3.31	3.10	2.88	2.64	2.38	2.10	1.80	1.48	1.14	.78	0.40	
5 to 0	3.73	3.52	3.30	3.06	2.80	2.52	2.22	1.90	1.56	1.20	.82	0.42

TABLE 6.—*Cumulative time of fall for 350-μ particles*

[Cumulative time of fall (hours)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	0.07											
115 to 110	.14	0.07										
110 to 105	.21	.14	0.07									
105 to 100	.27	.20	.13	0.06								
100 to 95	.33	.26	.19	.12	0.06							
95 to 90	.40	.33	.26	.19	.13	.07						
90 to 85	.47	.40	.33	.26	.20	.14	0.07					
85 to 80	.55	.48	.41	.34	.28	.22	.15	0.08				
80 to 75	.63	.56	.49	.42	.36	.30	.23	.16	0.08			
75 to 70	.72	.65	.58	.51	.45	.39	.32	.25	.17	0.09		
70 to 65	.81	.74	.67	.60	.54	.48	.41	.34	.26	.18	0.09	
65 to 60	.91	.84	.77	.70	.64	.58	.51	.44	.36	.28	.19	0.10
60 to 55	1.02	.95	.88	.81	.75	.69	.62	.55	.47	.39	.30	.21
55 to 50	1.14	1.07	1.00	.93	.87	.81	.74	.67	.59	.51	.42	.33
50 to 45	1.27	1.20	1.13	1.06	1.00	.94	.87	.80	.72	.64	.55	.46
45 to 40	1.41	1.34	1.27	1.20	1.14	1.08	1.01	.94	.86	.78	.69	.60
40 to 35	1.56	1.49	1.42	1.35	1.29	1.23	1.16	1.09	1.01	.93	.44	.75
35 to 30	1.72	1.65	1.58	1.51	1.45	1.39	1.32	1.25	1.17	1.09	1.00	.91
30 to 25	1.89	1.82	1.75	1.68	1.62	1.56	1.49	1.42	1.34	1.26	1.17	1.08
25 to 20	2.07	2.00	1.93	1.86	1.80	1.74	1.67	1.60	1.52	1.44	1.35	1.26
20 to 15	2.26	2.19	2.12	2.05	1.99	1.93	1.86	1.79	1.71	1.63	1.54	1.45
15 to 10	2.46	2.39	2.32	2.25	2.19	2.13	2.06	1.99	1.91	1.83	1.74	1.65
10 to 5	2.67	2.60	2.53	2.46	2.40	2.34	2.27	2.20	2.12	2.04	1.95	1.86
5 to 0	2.89	2.82	2.75	2.68	2.62	2.56	2.49	2.42	2.34	2.26	2.17	2.08

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115												
115 to 110												
110 to 105												
105 to 100												
100 to 95												
95 to 90												
90 to 85												
85 to 80												
80 to 75												
75 to 70												
70 to 65												
65 to 60												
60 to 55	0.11											
55 to 50	.23	0.12										
50 to 45	.36	.25	0.13									
45 to 40	.50	.39	.27	0.14								
40 to 35	.65	.54	.42	.29	0.15							
35 to 30	.81	.70	.58	.45	.31	0.16						
30 to 25	.98	.87	.75	.62	.48	.33	0.17					
25 to 20	1.16	1.05	.93	.80	.66	.51	.35	0.18				
20 to 15	1.35	1.24	1.12	.99	.85	.70	.54	.37	0.19			
15 to 10	1.55	1.44	1.32	1.19	1.05	.90	.74	.57	.39	0.20		
10 to 5	1.76	1.65	1.53	1.40	1.26	1.11	.95	.78	.60	.41	0.21	
5 to 0	1.98	1.87	1.75	1.62	1.48	1.33	1.17	1.00	.82	.63	.43	0.22

Reference for pp 3358 441-58

MAY 24, 1957.

TECHNICAL PRESENTATION FOR THE JOINT COMMITTEE ON ATOMIC ENERGY HEARINGS ON THE SUBJECT, THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN, MAY 27–29 AND JUNE 3–7, 1957

Specifically on—

Topic VI. Atmospheric Transport, Storage, and Removal of Particulate Radioactivity
Topic VII. Local Fallout
Topic VIII. Delayed Fallout

Submitted by James G. Terrill, Jr.,* Chief, Radiological Health Program, Division of Sanitary Engineering Service, Public Health Service, United States Department of Health, Education, and Welfare

VI. ATMOSPHERIC TRANSPORT, STORAGE, AND REMOVAL OF PARTICULATE RADIOACTIVITY

Public Health Service fallout activities have emphasized the collection of data on the actual exposure of people which data can be used to modify operational procedures to reduce the exposures and to serve as a basis for studying possible chronic radiation effects.

B. Local fallout

Local fallout is initially of concern as an acute external gamma or beta irradiation hazard. For this reason our off-site radiological safety operations in Nevada and in the Pacific are based on external gamma readings obtained with portable survey instruments. This system of operation is based on the assumption that beta concentrations during this period are substantially in proportion to the gamma intensities. This assumption has been confirmed, in general, by results of beta measurements of air samples collected during the fallout periods in Nevada. Local fallout may, and has become of concern as an internal beta emitter after it decay to a level at which the gamma irradiation is no longer of concern from the standpoint of acute effects. Up to this time the Service has not attempted to measure alpha concentrations in local (or delayed) fallout although the amounts are presumed to be low.

A report of local fallout sufficiently detailed to be used for public health purposes is the Report of Off-Site Radiological Safety Activities from Operation Teapot conducted at the Nevada test site in the spring of 1955, prepared jointly by the Las Vegas Branch Office of the Atomic Energy Commission and the Public Health Service.[1] Comments concerning the predictability of local fallout and observed patterns of local fallout will be based on this report.

The Teapot report outlines Public Health Service responsibilities and the supporting services, including air support, provided by other agencies.

Data gathered during this operation make it possible to:

1. Compare predicted fallout with the fallout as it actually occurred;
2. Compare the radioactive cloud path with the deposition of activity on the ground; and
3. Report on observed patterns of local fallout in terms of external gamma radiation.

1. The predictability of local fallout.—Fourteen devices were detonated during Operation Teapot. In reviewing the data on predicted and measured fallout from these detonations, it was found that in 5 cases the prediction is in substantial agreement with measured fallout, while in 6 cases the actual deposition of fallout was significantly at variance with the prediction. Three devices were detonated and no fallout prediction per se was used. Chart I illustrates a case where the fallout prediction compares favorably with the fallout which actually occurred. Chart II shows a typical deviation from the predicted fallout, while chart III shows a major deviation from the prediction.[1]

* Graduated from the University of Cincinnati in 1937 with a degree in civil engineering. Studied public health engineering at the Massachusetts Institute of Technology Graduate School from 1938–41. Since 1941 he has been active in the Public Health Service. He participated in the first Bikini tests. During the period 1948–51 he studied radiological defense under the sponsorship of the Armed Forces special weapons project at the Navy Postgraduate School and the University of California. He participated in and directed the Public Health Service activities related to the Nevada and Pacific test operations during 1953–57. Active in radiological committees of the American Society of Civil Engineers and the American Public Health Association. Member of the National Committee on Radiation Protection and the Nuclear Standards Board of the American Standards Association. Presently chief of the radiological health program, Division of Sanitary Engineering Services, Public Health Service. (Submitted by witness.)

[1] Report of Off-Site Radiological Safety Activities, Operation Teapot, Nevada test site, spring 1955.

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treatment, such as ion exchange removal, increases tremendously. The requirements in treatment materials in quantity alone is probably prohibitive. At the present time we cannot state that modern water-treatment methods applicable to the general population offer substantial protection against fallout.

* indicates those Redwing reports that were used.

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* Unpublished report, Radiation Exposures Received on Populated Atolls as ... sult of Operation Redwing. (See p. 441.)

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Limitations of Water Treatment Methods for Removing Radioactive Con... nants, by C. P. Straub, Public Health Reports, No. 70, 897 (1955).

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Measurement of Low-Level Radioactivity in Water, by L. R. Setter and ... Goldin, Journal American Water Works Association, volume 48, No. 11, ... ber 1956.

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... OF OFF-SITE RADIOLOGICAL SAFETY ACTIVITIES—OPERATION TEAPOT, NEVADA TEST SITE, SPRING, 1955

... for the Test Division, Santa Fe Operations Office, United States Atomic ... Commission; prepared by J. B. Sanders, Branch Manager, Las Vegas ... h Office, AEC; O. R. Placak, Off-Site Radiological Safety Officer, PHS; ... Carter, Deputy Off-Site Radiological Safety Officer, PHS

PURPOSE

... urpose of this report is to present a concise summary of off-site rad-safe ... es during Operation Teapot and to serve as a source of information to ... ed AEC and health agency personnel. All pertinent data necessary to ... the exposure effects of the operation in populated areas are included. ... interests of brevity, selected data only are given for nonpopulated areas. ... te monitoring logs and detailed film badge results covering these areas ... wever, available from the files of the Las Vegas Branch Office, AEC.

PLAN OF REPORT

... report is composed of the following general sections:

... AEC radiological criteria for the protection of the public.

... Off-site Rad-Safe Organization.

... Methods and equipment used.

... Public relations.

... sumé of individual shots are also included.

... individual sections cover the following materials: A summary of moni... ... uns and dosages, airway closures, cloud tracking, and low-level terrain

Georef letter	Longitude	Georef letter	Latitude
[illegible]	120°00′W.		
[illegible]	119°00′		
[illegible]	118°00′	C	32°00′N.
[illegible]	117°00′	D	33°00′
[illegible]	116°00′	E	34°00′
[illegible]	115°00′	F	35°00′
[illegible]	114°00′	G	36°00′
[illegible]	113°00′	H	37°00′
[illegible]	112°00′	J	38°00′
[illegible]	111°00′	K	39°00′
[illegible]	110°00′	L	40°00′
[illegible]	109°00′	M	41°00′
[illegible]	108°00′	N	42°00′
[illegible]	107°00′	P	43°00′
[illegible]	106°00′		

Similarly, the 2 groups of 2 members each denote, respectively, minutes of longitude and minutes of latitude within the 1° quadrangle specified by the letter group. To provide an example, the coordinates of Las Vegas are EG 5120. The identification of the 15° quadrangle (EJ) is omitted for the reason previously stated.

EG identifies the 1° quadrangle.
51 identifies the Georef minute of longitude.
20 identifies the Georef minute of latitude.

[illegible] Exposures Received on Populated Atolls as a Result of Operation Redwing

During Operation Redwing 4 gamma intensity readings daily were taken at [illegible] off-site atolls utilizing a radiac meter AN/PDR-27F, calibrated against [illegible] consisting of 7 micrograms of radium. Following each test, hourly [illegible] were taken for an interval of time dependent upon fallout forecasts, [illegible] conditions at and following test time, cloud tracking, and readings obtained [illegible] atolls. The attached tables and charts show the weighted daily averages [illegible] readings for the atolls at which stations were maintained.

[illegible] estimated cumulative exposure of the populations of these atolls resulting [illegible] Operation Redwing has been computed based on these meter readings. Net [illegible] (above preoperation background) have been utilized. Where a residual [illegible] remained at the time the stations were inactivated, the 70-year exposure [illegible] residual was computed based on the equation $I_1T_1^{-k}=I_2T_2^{-k}$. Based [illegible] decay data, k=1.2 was utilized. It will be noted that the last day's [illegible] Ujelang was 1.5 mr/hr. This was due to the test of July 21. The [illegible] record shows that fallout had stopped and radiation intensities were [illegible] at the time the station was inactivated. A reduction factor to de[illegible] effective biological dose was not utilized as conditions under which the [illegible] are not believed to warrant the commonly accepted reduction factor. [illegible] involved are attached. On this basis, 70-year external gamma [illegible] resulting from Operation Redwing are as follows:

[illegible]ang Atoll: 560 mr.
[illegible]ik Atoll: 53 mr.
[illegible]tho Atoll: 616 mr.
[illegible]gerick Atoll: 853 mr.

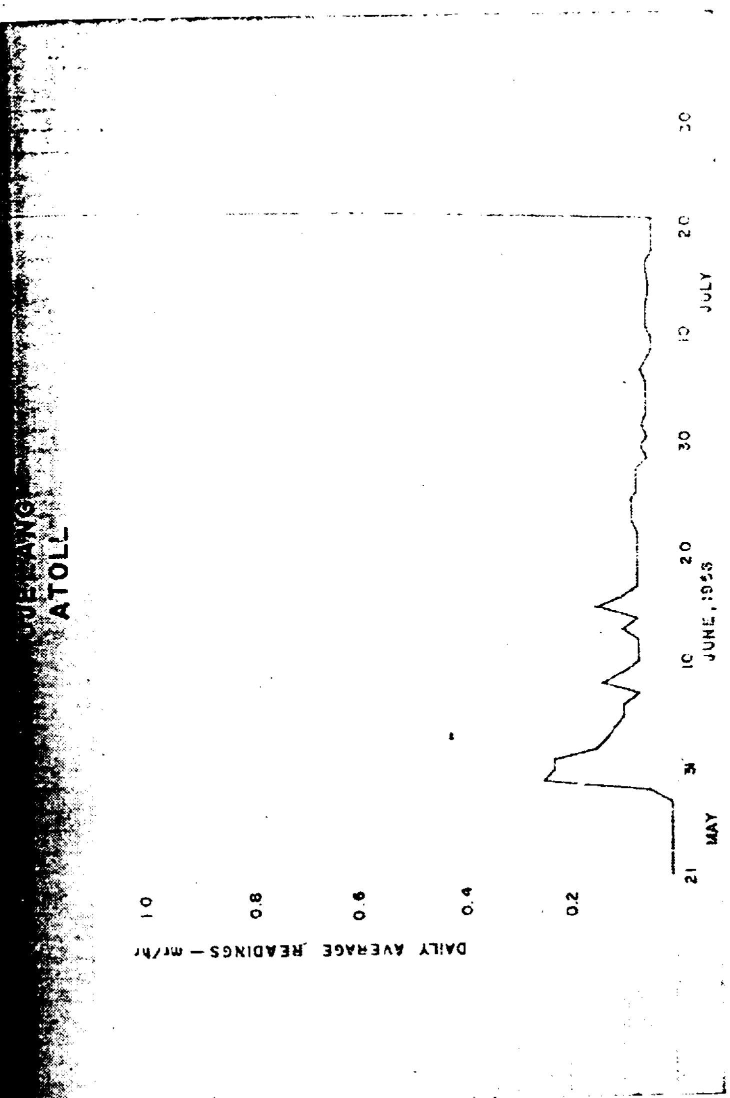
[illegible] attached is a plot showing AN/PDR-27F readings at JTF-7 Headquar[illegible] Island, during the period July 21 to July 23, 1956. On the basis [illegible] figures, effective external gamma doses to various periods of time have [illegible] computed as follows:

[illegible] 5 days: 3.45 R.
[illegible] 15 days: 5.7 R.
[illegible] 1 year: 7.95 R.
[illegible] dose: 12.45 R.

[illegible] are attached.

Daily average readings

Date	Ujelang	Utirik	Wotho	Rongerik	Date	Ujelang	Utirik	Wotho
Apr. 26	0.01	0.02	0.01	0.1	June 26	.07	.02	.3
May 29	.05	.03	.2	.15	June 27	.07	.02	.25
May 30	.25	.03	4.5	.30	June 28	.07	.06	.25
May 31	.26	.26	.26	.26	June 29	.05	.15	.23
June 1	.23	.03	1.0	3.0	June 30	.06	.15	.23
June 2	.15	.03	.85	3.0	July 1	.05	.15	.21
June 3	.13	.02	.75	3.0	July 2	.06	.11	.21
June 4	-------	.02	-------	2.0	July 3	.05	.11	.19
June 5	.1	.02	.5	2.0	July 4	.05	.10	.18
June 6	.1	.02	.4	2.0	July 5	.05	.10	.18
June 7	.07	.02	.3	2.0	July 6	.05	.08	.18
June 9	-------	-------	-------	1.5	July 7	.05	.08	.15
June 10	-------	-------	-------	1.0	July 8	.05	.07	.14
June 11	-------	-------	-------	1.0	July 9	.04	.07	.14
June 12	.07	.02	.2	1.0	July 10	.04	.05	.11
June 13	.1	.02	.18	1.0	July 11	.05	.06	.11
June 14	.07	.02	.48	2.0	July 12	.05	.05	.12
June 15	.15	.02	.90	1.5	July 13	.05	.05	.10
June 16	.1	.04	.8	1.0	July 14	.045	.04	.10
June 17	.07	.05	.7	1.0	July 15	.045	.045	.10
June 18	.07	.04	.6	1.0	July 16	.05	.05	.09
June 19	.07	.04	.7	1.0	July 17	.05	.04	.08
June 20	.07	.03	.6	1.0	July 18	.04	.05	.08
June 21	.07	.02	.5	1.0	July 19	.04	.04	.08
June 22	.07	.02	.5	1.0	July 20	.04	.04	.08
June 23	.08	.03	.4	1.0	July 21	.04	.04	.18
June 24	.08	.02	.4	.75	July 22	.6	.04	.18
June 25	.08	.03	.3	.5	July 23	1.5	-------	-------

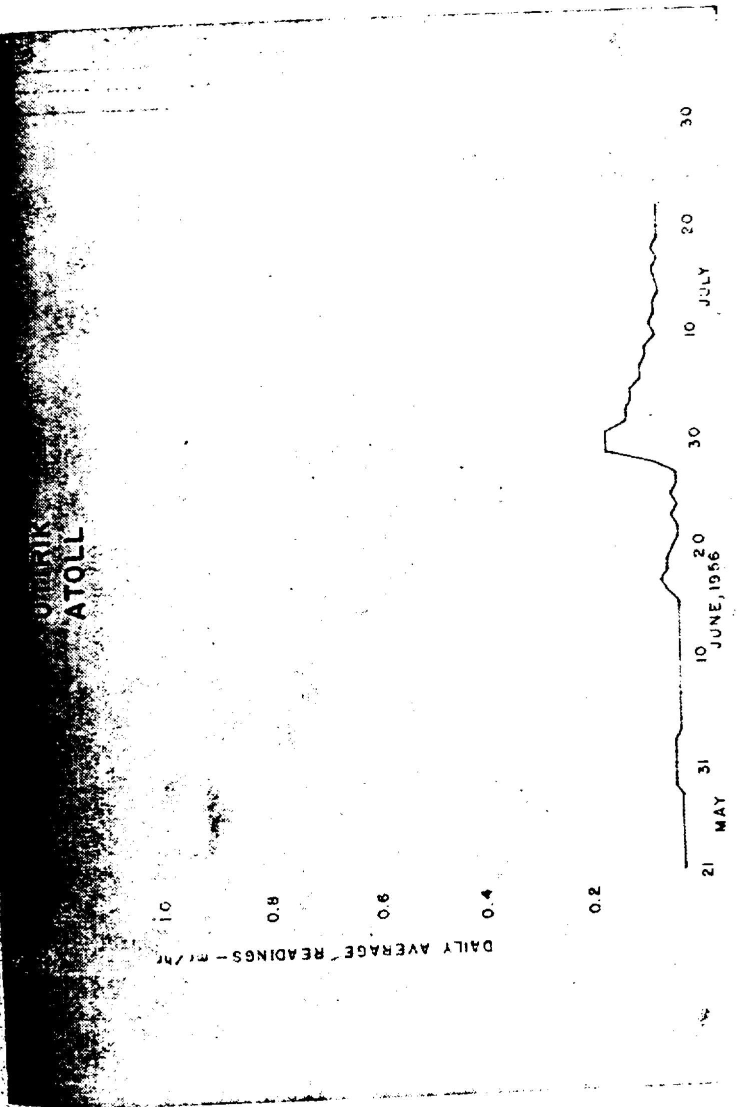

ATOLL
DAILY AVERAGE READINGS — mr/hr
1.0
0.8
0.6
0.4
0.2
21
MAY
31
10
20
JUNE, 1953
30
10
JULY
20
30

Cumulative exposure computations—Ujelang

Rate mr./hr.	Days	Hours	Dose mr.	Rate mr./hr.	Days	Hours	Dose mr.
0.04	13	312	12.48	0.07	3	72	[illegible]
0.24	1	24	5.76	0.13	1	24	[illegible]
0.23	1	24	5.52	0.10	3	72	[illegible]
0.22	1	24	5.28	0.05	4	96	[illegible]
0.14	2	48	6.72	0.03	6	144	[illegible]
0.12	1	24	2.88	0.035	2	48	[illegible]
0.11	1	24	2.64	1.5	1	24	[illegible]
0.09	4	96	8.64				
0.06	12	288	17.28	Total			[illegible]

TEWA H=210600 M
240000 M=H+66 hours=2.75 days
70 year dose after this time=approx. 430 mr. assuming $I_2T_2^{1.2}=I_1T_1^{1.2}$
Total 70 year dose=130+430=560 mr.

[1] Rate above preoperation background of 0.01 mr./hr.
[2] Through July 23.


ATOLL
DAILY AVERAGE READINGS
1.0
0.8
0.6
0.4
0.2
21
MAY
31
10
20
JUNE, 1956
30
10
JULY
20
30

Cumulative exposure computation—Utirik

Rate [1] mr./hr.	Days	Hours	Dose mr.	Rate [1] mr./hr.	Days	Hours	Dose mr.
0.01	8	192	1.92	0.09	2	48	4.[illegible]
0.02	9	216	4.32	0.08	2	48	3.[illegible]
0.025	1	24	0.60	0.06	2	48	3.[illegible]
0.03	6	144	4.32	0.05	2	48	2.[illegible]
0.04	2	48	1.92				
0.13	3	72	9.36	Total			36.[illegible]

[1] Rate above preoperation background of 00.2 mr./hr.

Assume D=June 27
70-year dose from July 23=approx. 17 mr.
Total 70-year dose=36+17=53 mr.

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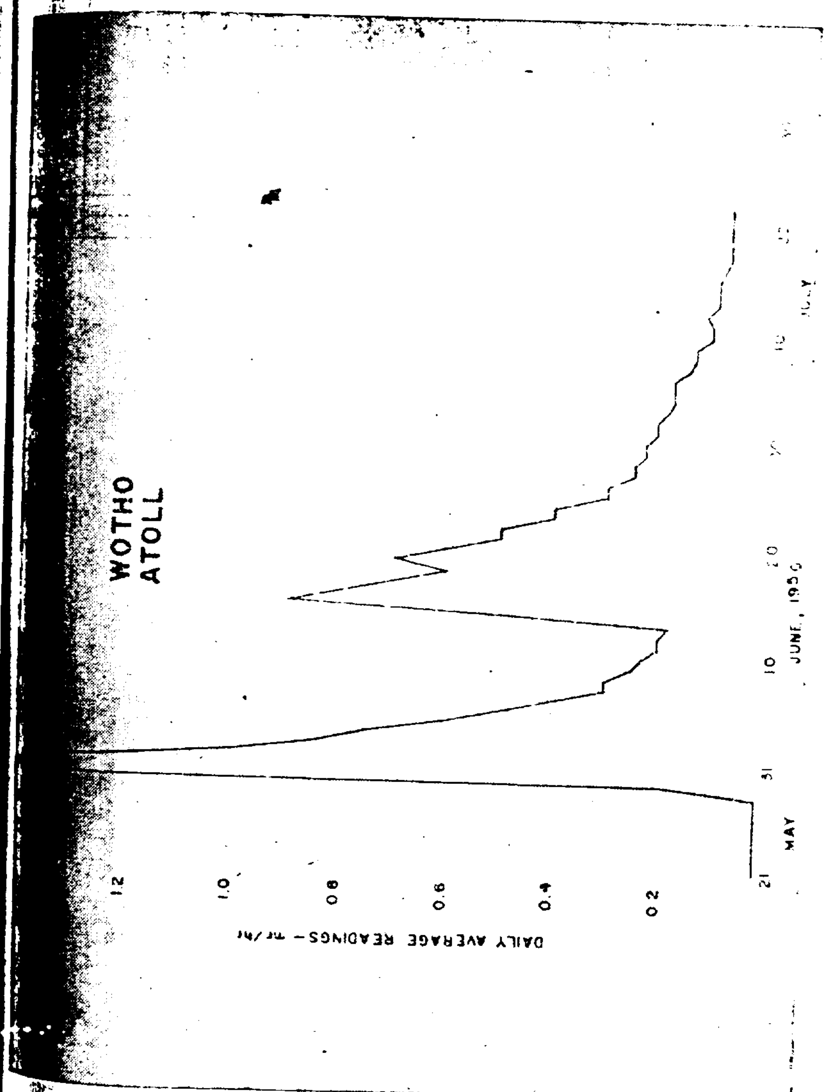
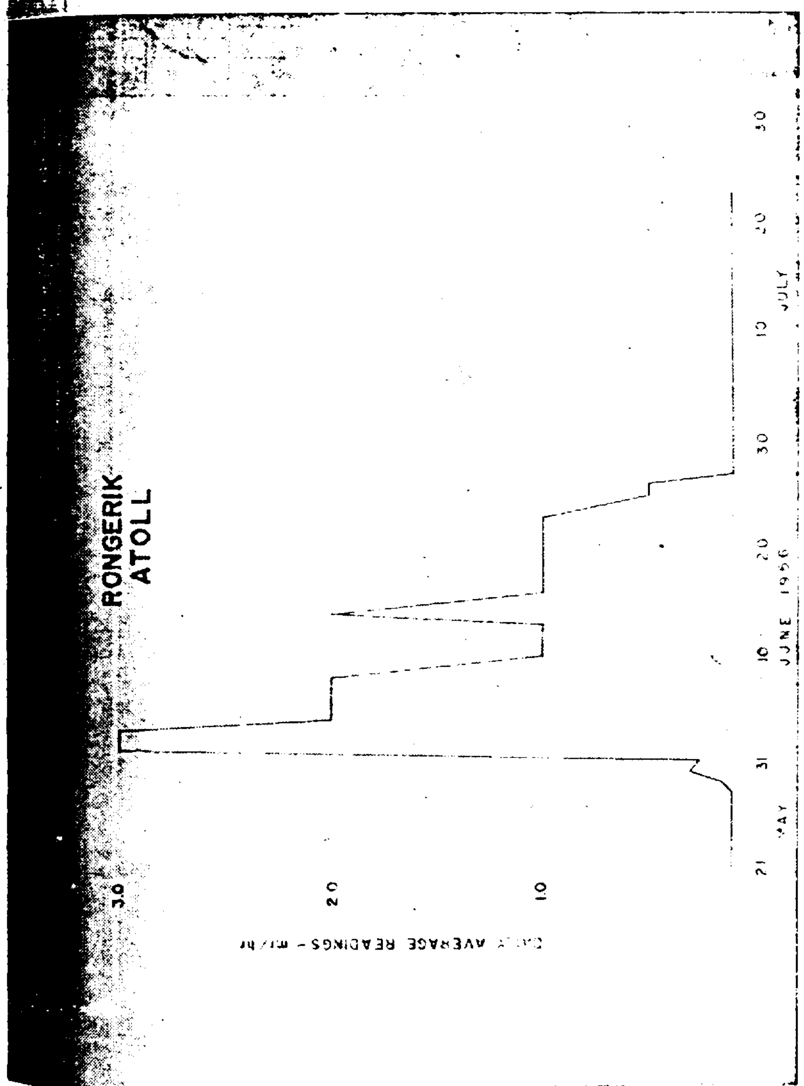


Cumulative exposure computation—Wotho

Rate [1] mr/hr.	Days	Hours	Dose mr.	Rate [1] mr/hr.	Days	Hours	Dose mr.
0.01	1	24	0.24	0.17	4	96	[illegible]
4.5	1	24	108.00	0.47	1	24	[illegible]
2.75	1	24	66.00	0.89	1	24	[illegible]
1.0	1	24	24.00	0.79	1	24	[illegible]
0.84	1	24	20.16	0.69	2	48	[illegible]
0.74	1	24	17.76	0.59	2	48	[illegible]
0.62	1	24	14.88	0.14	1	24	[illegible]
0.49	3	72	35.28	0.13	2	48	[illegible]
0.39	3	72	28.08	0.10	2	48	[illegible]
0.29	3	72	20.88	0.11	1	24	[illegible]
0.19	1	24	4.56	0.09	3	72	[illegible]
0.24	3	72	17.28	0.08	1	24	[illegible]
0.22	2	48	10.56	0.07	6	144	[illegible]
0.20	2	48	9.60				
0.18	1	24	4.32	Total			[illegible]

6/13 = H
7/23 = H + 40 d
70 year dose = 79 mr
Total 70 year dose = 546 + 70 = 616 mr.

[1] Above preoperation level of 0.01 mr/hr.
[2] Through July 22, 1956.

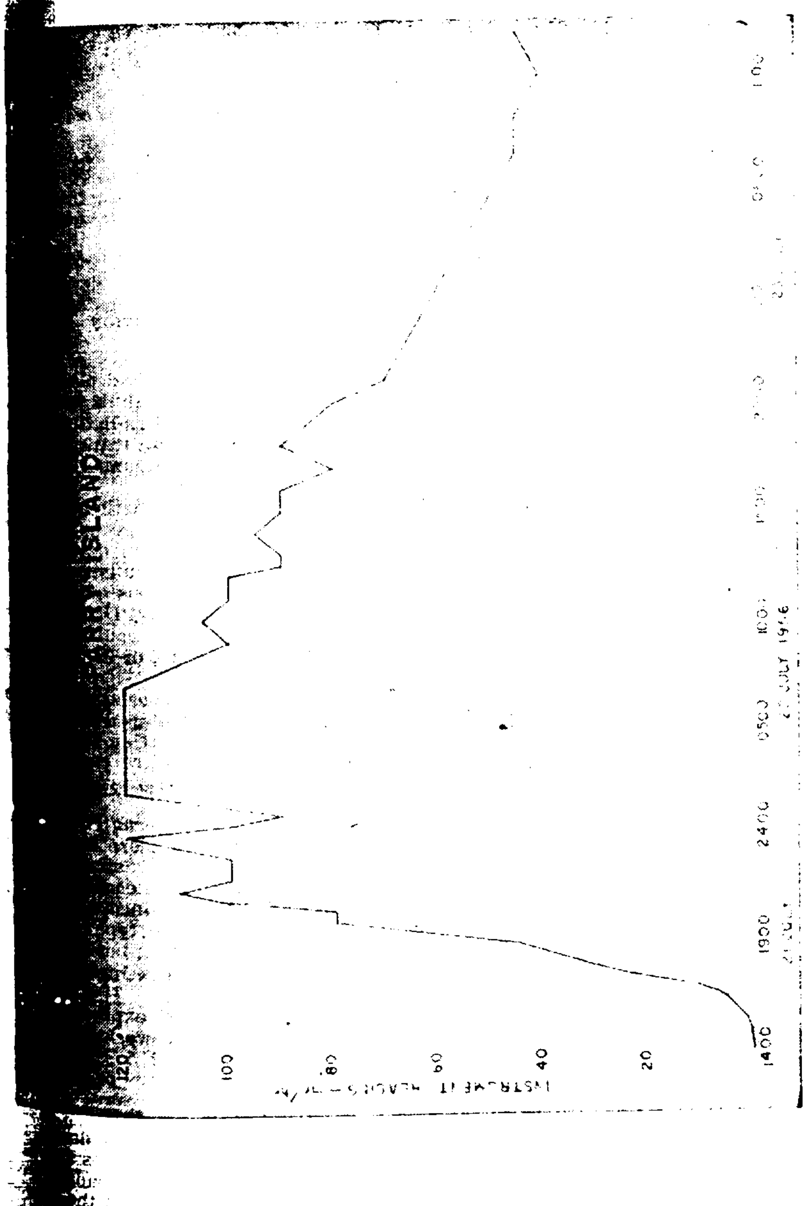

RONGERIK ATOLL
DAILY AVERAGE READINGS - mr/hr
3.0
2.0
1.0
21
MAY
31
10
JUNE 1956
20
30
10
JULY
20
30

Cumulative exposure computation—Rongerik

Rate [1] mr/hr	Days	Hours	Dose mr.	Rate [1] mr/hr.	Days	Hours	Dose mr.
0.05	1	24	1.20	0.9	12	[illegible]	[illegible]
0.2	1	24	4.80	0.65	1	24	[illegible]
0.16	1	24	3.84	0.4	2	48	[illegible]
2.9	3	72	208.80	Total			[illegible]
1.9	6	144	273.60				
1.4	2	48	67.20				

[1] Above preoperation level of 0.1 mr/hr.

Days	Hours	Dose
12	288	[illegible]
1	24	[illegible]
2	48	[illegible]
		[illegible]



DOSE CALCULATIONS FOR PARRY ISLAND

Accumulated dose to 220700 M was 0.6R
At that time decay started with the decay constant $K=-1.2$
Personnel leaving at H+5 days will receive:

$$16-12+0.6=4.6 \text{ R}$$

If this is reduced by 25 percent, the effective dose=3.45 R
Permanent personnel will receive:
For first 15 days:

$$16-9+0.6=7.6 \text{ R}$$

Effective 15 day dose=(0.75) (7.6) =5.7 R
For 15 days to 1 year:

$$9-4.5=4.5 \text{ R}$$

Effective dose=(0.5) (4.5) =2.25 R
Total effective dose to end of 1 year=7.95 R
Infinity dose for permanent personnel:

$$7.95+4.5=12.45 \text{ R}$$

REPORT ON EXPERIMENTAL FILM BADGE STUDY DURING OPERATION REDWING
OCTOBER 1, 1956

During Operation Redwing the Public Health Service group had planned, on an experimental basis, to utilize film badges on the off-site atolls of Utirik, Ujelang, and Wotho as a method of securing a figure for total radiation dose on these islands. Arrangements were made for the procurement, transportation and processing of film badges with task group 7.1 radsafe personnel and task group 7.4 nuclear research officer, Lt. W. J. Jameson.

The first group of film badges, enclosed in rigid, transparent plastic containers were exposed for a period of approximately 50 days. A second group was sent out to the atolls and exposed for a period of approximately 15 days. When these films were developed and read, it was found that the results were much higher (up to 5 to 10 times) than would be expected on the basis of exposures computed from instrument readings taken at the atolls (AN/PDR27F geiger counters were used). On examination of the films, water marks could be clearly seen on most of them. It was theorized that heat or moisture, or both, was the cause of the high readings.

Capt. B. H. Purcell, task group 7.1, arranged to have some special film badges prepared. One lot was prepared by having the film packet dipped in Ceresin wax before sealing in the plastic case (referred to in this report as "film dipped badges"). The second lot was prepared by dipping the entire case in wax after the uncoated film packet was sealed in the pastic case (referred to in this report as "case dipped badges").

Preliminary work done on these badges by exposing them alternately to steam and then placing in a refrigerator indicated that they were more resistant to moisture than the regular badges. It was decided to place approximately 20 of each type on each off-site atoll, bringing in 3 sets from each atoll each week so the reliable life of each type of badge in the field could be determined. (Only half as many film dipped badges were available as the other two types.) Unfortunately, for the purposes of this test, the operation terminated before it could be completed. It is believed, however, that some tentative conclusions can be reached from the results obtained.

Films were collected after approximately 1 and 2 weeks' exposures. The balance of the films were collected after approximately 3 weeks' exposure. Readings taken on the films were compared with calculated doses based on instrument readings taken during the same periods. Tabulations of the results are attached.

It can be seen that the doses received during the first week are too low to give reliable results on the film badges used, while exposures received during the first 2 weeks are just at the borderline of sensitivity. All film badges appeared to be satisfactory after 1 week, but after 2 weeks the regular badges were showing signs of moisture penetration. After 3 weeks, almost all the regular badges, while none of the film-dipped or case-dipped badges, were watermarked.

Estimating the dose to which the films brought in after 3 weeks were exposed is complicated by the fact that Parry Island had a gamma radiation level of 20 to 70 mr/hr at the time the films reached there. Thus, it has been necessary to estimate exposure received at Eniwetok Atoll prior to development.

ever, a study of the results on these badges is believed to indicate a trend. Attached are curves showing the distribution of results for each type of film from each atoll and the results for each type of film from the three atolls combined.

Considering this latter curve, if one considers results within 50 percent of a "true" (in this case, calculated) dose to be satisfactory, it can be seen that 68 percent of the film-dipped badges and 60 percent of the case-dipped badges fall within this range, while only 19 percent of the regular badges meet this criterion. This is admittedly a limited sample, but the results are believed to warrant the following conclusions and recommendations:

1. Climatic conditions at the Pacific Proving Grounds have an adverse effect on ordinary film badges to the extent that they cannot be relied upon to give satisfactory results;

2. If possible, a study should be made to determine the reliable life of wax-coated film badges and possibly other types of dosimeters) under climatic conditions similar to those at Pacific Proving Grounds prior to the next test series. If this is not possible, such a study should be conducted at Pacific Proving Grounds during the next series.

3. For area monitoring of this type, a more sensitive film should be included in the film packet.

Experimental film badges—Ujelang Atoll

Station No.	Date out	Date in	Time exposed, in days	Indicated dose, milliroentgen			Calculated dose, milliroentgen
				Regular	C. D.	F. D.	
[illegible]	July 4, 1956	July 10, 1956	7	[1] 50	30		8
[illegible]	do	do	7	70	30	30	8
[illegible]	do	July 17, 1956	13	[1] 70	0	0	16
[illegible]	do	do	13	[1] 90	30		16
[illegible]	do	July 26, 1956	23	[1] 210	90	70	143
[illegible]	do	do	23	[1] 245	90		143
[illegible]	do	do	23	[1] 210	110	70	143
[illegible]	do	do	23	[1] 225	110	90	143
[illegible]	do	do	23	[1] 350	110		143
[illegible]	do	do	23	[1] 170	90	70	143
[illegible]	do	do	23	[1] 245	130		143
[illegible]	do	do	23	[1] 280	110		143
[illegible]	do	do	23	[1] 280	110	90	143
[illegible]	do	do	23	[1] 245	90		143
[illegible]	do	do	23	[1] 330	110		143
[illegible]	do	do	23	[1] 265	90	70	143
[illegible]	do	do	23	[1] 225	50	70	143
[illegible]	do	do	23	[1] 265	110	110	143

[1] Film watermarked.

Experimental film badges—Utirik Atoll

Station No.	Date out	Date in	Time exposed, in days	Indicated dose, milliroentgen			Calculated dose, milliroentgen
				Regular	C. D.	F. D.	
[illegible]	July 8, 1956	July 14, 1956	7	70	50	50	9.0
[illegible]	do	do	7	70	50		9.0
[illegible]	do	July 26, 1957	19	90	70		41.5
[illegible]	do	do	19	[1] 470	425	410	41.5
[illegible]	do	do	19	470	440		41.5
[illegible]	do	do	19	110	70	[2] 365	41.5
[illegible]	do	do	19	110	70		41.5
[illegible]	do	do	19	[1] 130	50	50	41.5
[illegible]	do	do	19	[1] 130	70		41.5
[illegible]	do	do	19	[1] 130	50	50	41.5
[illegible]	do	do	19	[1] 130	70		41.5
[illegible]	do	do	19	[1] 130	70	50	41.5
[illegible]	do	do	19	[1] 130	70		41.5
[illegible]	do	do	19	[3] 440	440	440	41.5
[illegible]	do	do	19	[1] 110	70		41.5
[illegible]	do	do	19	[1] 110	70	50	41.5
[illegible]	do	do	19	90	70		41.5
[illegible]	do	do	19	90	70		41.5

[1] Film watermarked.
[2] [illegible] developed separately from other films exposed during this same period.
[3] [illegible] due to unknown cause.

Experimental film badges—Wotho Atoll

Station No.	Date out	Date in	Time exposed, in days	Indicated dose, mr.			Calc… ed d… mr.
				Regular	C. D.	F. D.	
10	July 2, 1956	July 9, 1956	8	30	30	30	
9	do	July 16, 1956	15	70	30	30	
1	do	July 24, 1956	23	[1] 160	130	90	
2	do	do	23	[1] 180	130	90	
3	do	do	23	[1] 180	130	90	
4	do	do	23	[1] 180	130	110	
5	do	do	23	[1] 160	130	110	
6	do	do	23	[1] 220	130	110	
7	do	do	23	[1] 220	130	130	
8	do	do	23	[1] 270	110	130	
11	do	do	23	[1] 220	130	----------	
12	do	do	23	[1] 220	110	----------	
13	do	do	23	[1] 235	130	----------	
14	do	do	23	[1] 220	130	----------	
15	do	do	23	[1] 220	110	----------	
16	do	do	23	[1] 265	110	----------	
17	do	do	23	[1] 275	110	----------	
18	do	do	23	[1] 285	110	----------	
19	do	do	23	[1] 180	130	----------	
20	do	do	23	[1] 220	110	----------	

[1] Film watermarked.

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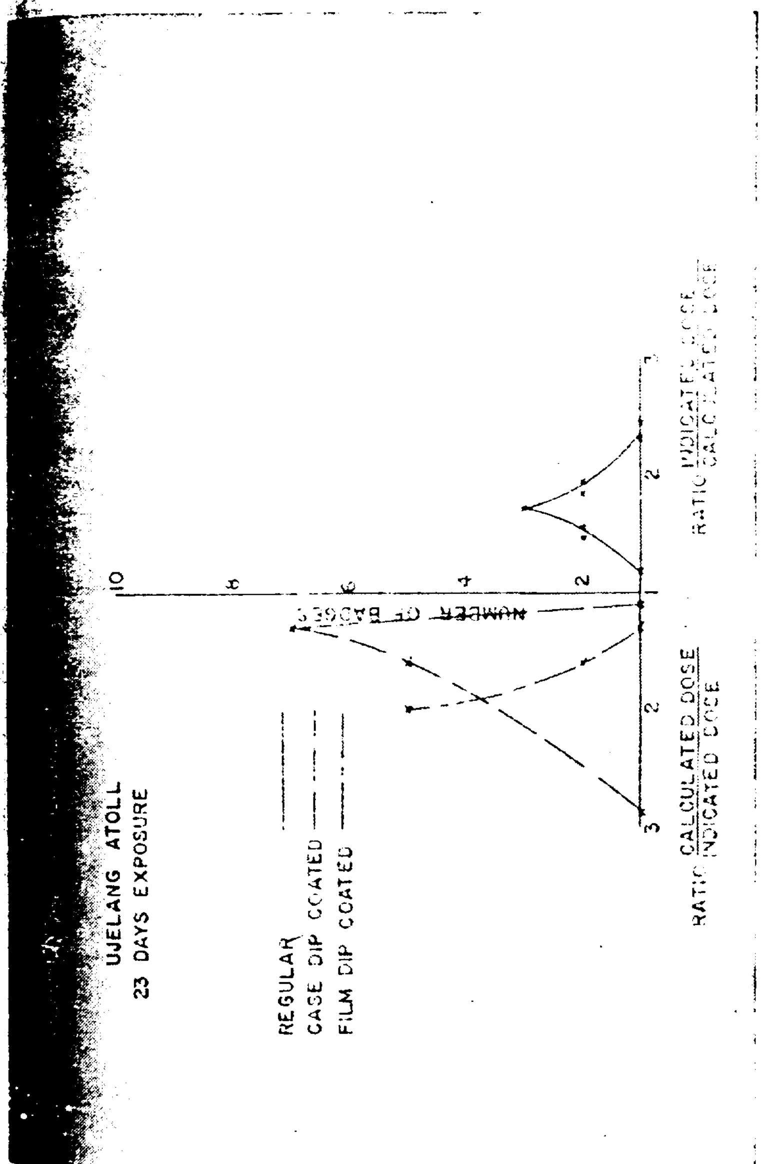
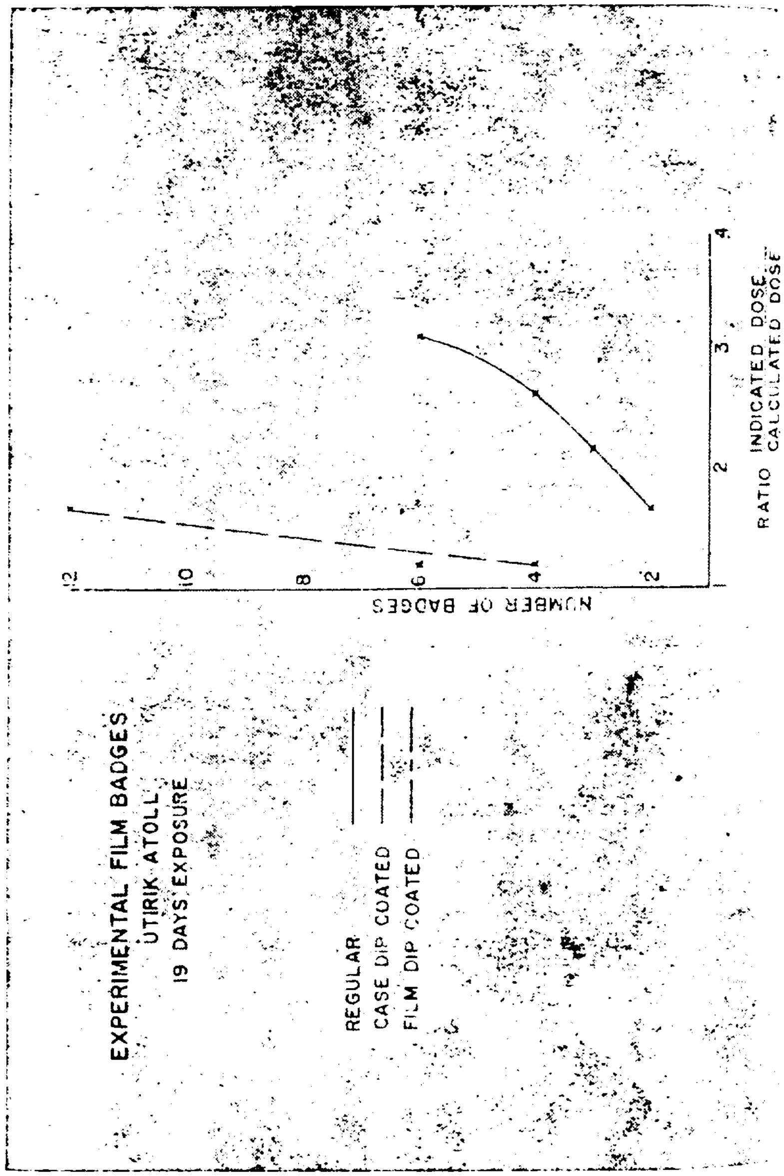
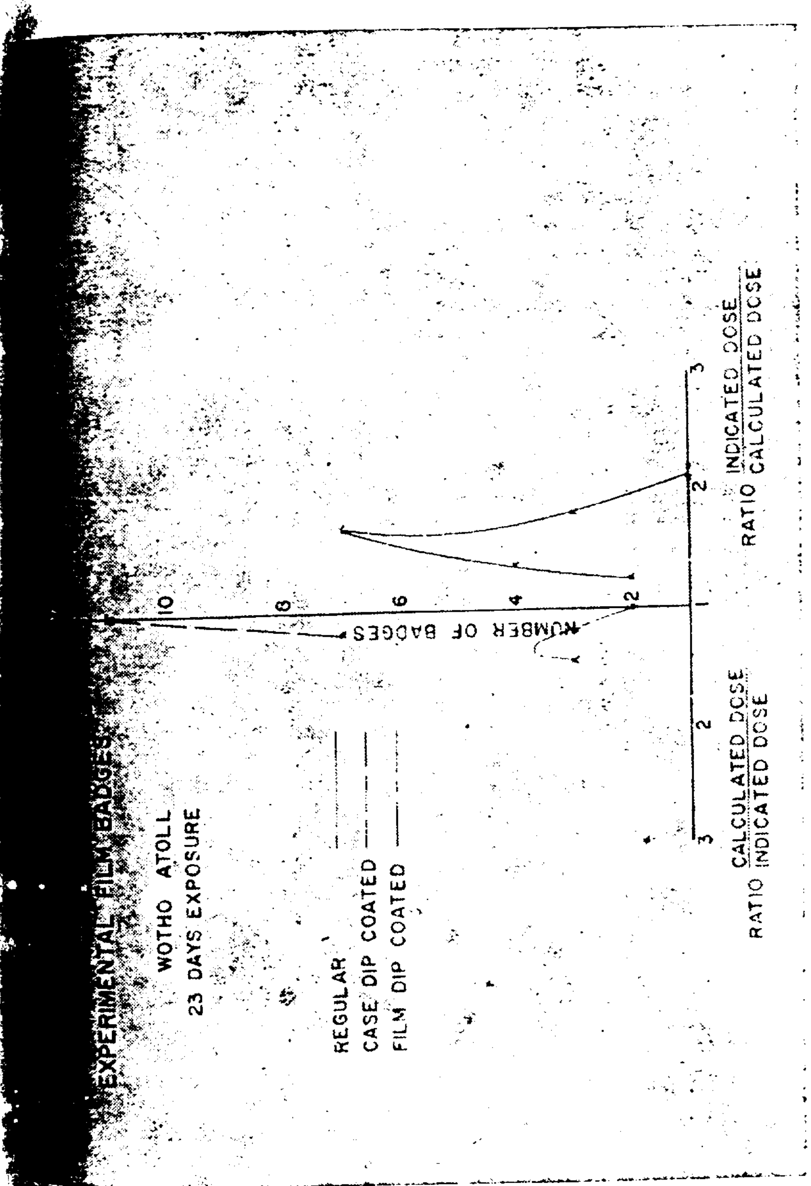
Title pgs.
21-23

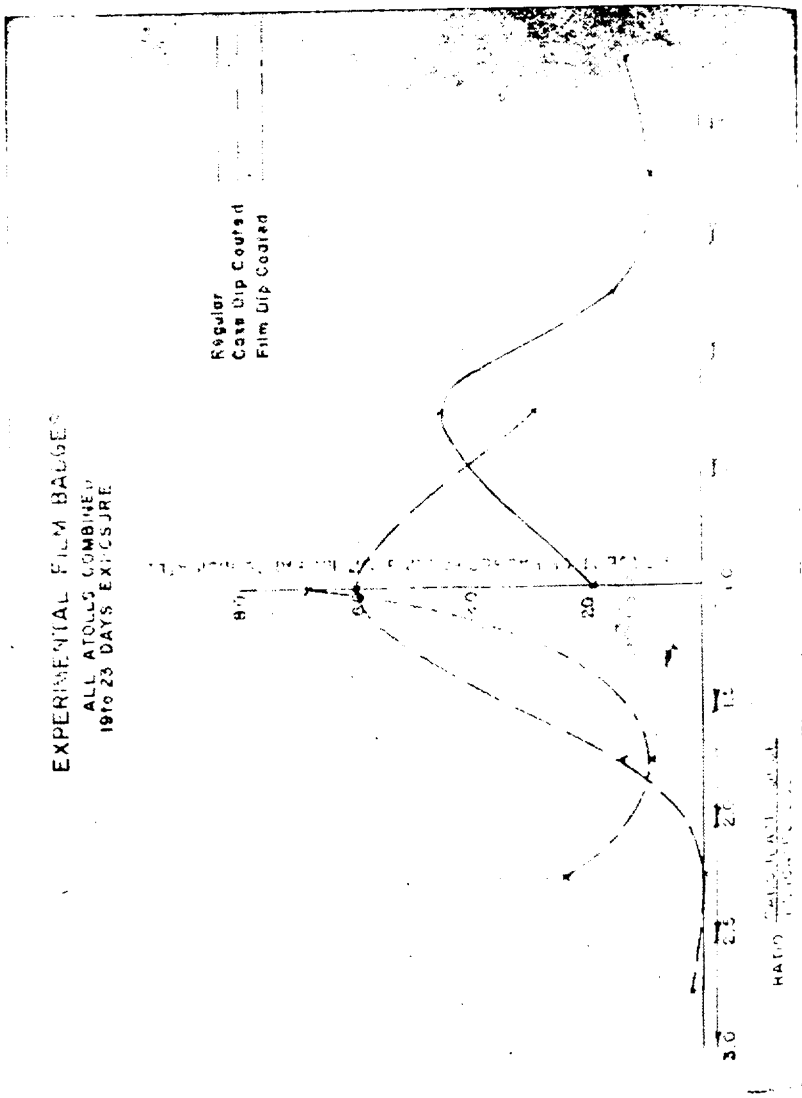
Atoll

…ndicated dose, mr.			Calc…ed d… mr.
…lar	C. D.	F. D.	
30	30	30	
70	30	30	
160	120	90	
180	130	90	
180	130	90	
180	120	110	
160	130	110	
220	130	110	
220	130	130	
270	110	130	
220	130	----------	
220	110	----------	
235	130	----------	
220	130	----------	
220	110	----------	
235	110	----------	
275	110	----------	
285	110	----------	
180	130	----------	
220	110	----------	




EXPERIMENTAL FILM BADGES
UTIRIK ATOLL
19 DAYS EXPOSURE
REGULAR
CASE DIP COATED
FILM DIP COATED
NUMBER OF BADGES
2
4
6
8
10
12
RATIO INDICATED DOSE / CALCULATED DOSE
2
3
4


EXPERIMENTAL FILM BADGES
WOTHO ATOLL
23 DAYS EXPOSURE
REGULAR
CASE DIP COATED
FILM DIP COATED
NUMBER OF BADGES
RATIO INDICATED DOSE / CALCULATED DOSE
RATIO CALCULATED DOSE / INDICATED DOSE


EXPERIMENTAL FILM BADGES
ALL ATOLLS COMBINED
19 to 23 DAYS EXPOSURE
Regular
Case Dip Coated
Film Dip Coated

semination of radioactive material from nuclear test areas outside of the continental United States, and the levels of activity which might occur in populated areas in the United States as a result. At many of the field sampling sites, there has been almost daily contact between the State health departments and the newspaper services.

PRELIMINARY RESULTS

During the entire 1956–57 sampling period, external gamma background radiation measurements have remained practically constant at all sampling stations. Depending upon the locality, the background varies from 0.01 to 0.035 milliroentgens per hour and, in general, is typical of that locality.

The beta activity of the particulates in air, having gross radioactive half lives longer than several days, showed minimum average concentrations varying from 0.5 to 1.0 uuc/M³ at the time of measurement (3 to 5 days after collection). An exception was Alaska, where minimum concentrations were about one-fifth or one-tenth those in the United States and Hawaii.

Before, during, and well after the period announced as encompassing Operation Redwing conducted by the United States at the Pacific Proving Ground in 1956, maximums of air concentrations were noted at all sampling stations, each lasting from several days to more than a week. The highest value, [illegible] micromicrocuries per cubic meter of air, was measured in Honolulu, with equally high values being observed in Austin, Tex., Indianapolis, Ind., Springfield, Ill., and Gastonia, N. C. The latter 4 occurred about 55 days after the announced termination of the United States 1956 tests at the Pacific Proving Ground, and it is difficult to associate these maximums with our tests, because of the long time interval.

Table 1 and figure 1, accompanying this report, illustrate the shift to higher air radioactivity levels at areas east and west of the Mississippi River, at Honolulu, and in Alaska, with the passage of time. The most significant shift to higher air activities occurred after September 1, 1956, at least 30 days after the announced termination of our test operations.

It has been possible to analyze a number of the samples find the approximate date of formation. It should be realized that this method indicates, within limits, the formative age of the more recent fission products in each sample, and is not intended to assess more than the short-term significance of the gross beta radioactivity. Figure 2 illustrates the results of this procedure, and strikingly shows that the major portion of the intermediate half-lived fission products which were samples in the United States could not have resulted from announced test series conducted by the United States. During the 1957 operation all samples will be dated.

Since January 1957, and continuing until the present time, air activity levels measured in the United States have been substantially higher at all locations than for comparable periods in previous years by a factor of about 5 to 10. The radiation samples, when dated, show approximate formative ages coinciding to a degree with publicly announced foreign nuclear tests. The effect is most noticeable in precipitation sample, as described in The Distribution of Radioactivity From Rain, by Dr. Lloyd R. Setter and Dr. Conrad P. Straub (presented for publication proceedings, American Geophysical Union Meeting, Washington, D. C., April 29 to May 1, 1957).

Provisional Permissible Concentr. of unknown mixt. of beta radio it.

The National Committee on Radiation Protection, in NBS Handbook 52, has suggested 10^{-9} uc/ml (1,000 uuc/M³) as the provisional level of permissible concentrations of unkown mixtures of beta-emitting radioisotopes in air. When it is reduced to 10 percent of that value as suggested for large population groups, namely, 100 uuc/M³, we realize that the measured levels of beta radioactivity in air, while generally below the recommended value, are more often approaching this level as time goes on.

Radiation surveillance network stations and operators

1-1	Hartford, Conn.	Omer C. Sieverding, assistant director, Bureau of Laboratories, Connecticut State Department of Health, State Office Building, Hartford, Conn.
1-2	Lawrence, Mass.	James L. Dallas, associate sanitary engineer, Massachusetts State Department of Health, Room 511, State House, Boston, Mass.

RADSAFE EMERGENCY INSTRUCTIONS FOR POPULATED ISLANDS

1. The commander, JTF-7, has designated a representative for each off-site location outside the PPG. For the populated islands near the PPG, the representative is responsible for the radiological safety of the local population and the members of the task force.

2. The representative of the task force commander is provided guidance as follows:

(a) The Marshallese magistrate and iroij if on hand and the Marshallese health aid and council on each atoll or island should be assured that every precaution has been taken to prevent exposure of the natives to radiation hazards resulting from fallout.

(b) The representative will consult with the local magistrate to insure that a method exists whereby all residents of an atoll may be summoned to a central location and evacuated by air or water transportation if a fallout emergency exists. A fallout emergency will be determined by the commander, JTF-7; however, the local representative will assume that a fallout emergency exists at such time as radiological survey instruments, when held at a position 3 feet above the ground, indicate a rate of 1r./hr.

(c) Should evacuation by air be necessary, baggage will be limited to that which each individual can carry or approximately 50 pounds. Whether evacuation is achieved by sea or air, no animals will be evacuated. A tabulation of animals left behind should be made as soon as possible to insure the accuracy of claims against the Government.

(d) The local magistrate should be informed that in event of an unforeseen emergency, doctors will be flown from the United States by special airlift to care for local inhabitants who will be evacuated to Kwajalein Atoll and that evacuation plans are in existence to permit the task force to cope with any emergency.

(e) Fallout of a dangerous nature can be suspected by the presence of a saltlike precipitate or unexpected mist. Should such an event take place, it should be confirmed by monitoring.

3. The representative will arrange through the local magistrate and native health aid to inform the Marshallese of the basic health measures that they may use to protect themselves from danger in case fallout is suspected or confirmed. These measures are:

(a) Remain indoors or under cover to protect themselves from the falling or settling radioactive particles.

(b) If particles settle on clothing, dust and shake off clothing.

(c) Bathe and keep clean. Particular attention should be given to washing under the arms, the groin, face, and hair.

(d) Keep food covered to prevent ingestion of fallout particles.

(e) Should the readings exceed 5 r./hr. it is recommended that the natives be advised to stand out in the water (ocean) and immerse themselves as often as practicable or keep themselves under water. This recommendation is based on the fact that water does extremely well in attenuating radiation.

(A report of the Radiological Health Branch, Bureau of State Services, Public Health Service, is inserted at this point in addition to the material submitted.)

RADIOLOGICAL HEALTH BRANCH,
BUREAU OF STATE SERVICES,
PUBLIC HEALTH SERVICE,
October 1952.

SUMMARY OF THE REPORTED RADIATION EXPOSURE IN THE UNITED STATES

I. INTRODUCTION

The program of the Radiological Health Branch, Public Health Service, is directed toward preventing the impairment of human well-being from accidental or unwise exposure to harmful amounts of ionizing radiations and toward improvement of health through judicious use of these radiations. This program can best be accomplished through cooperative efforts of the Radiological Health Branch and the State and local health agencies.

(82) Balber, David, Instrument Evaluation and Air Sampling, Health Physics Insurance Seminar, February 6–10, 1950, TID–388, pages 92–98, United States Atomic Energy Commission, Technical Information Service, Oak Ridge, Tenn.
(83) Eleventh Semiannual Report of the Atomic Energy Commission, January 1952, United States Government Printing Office, Washington 25, D. C.
(84) Advertisement: High Voltage Engineering Corporation—Nucleonics, June 1952, page 12.
(85) Ingram, M., Health Hazards in Radiation Work, Atomic Energy Commission project, the University of Rochester, report of October 25, 1950. UR–130.
(86) Abelson, P. H., and Kruger, P. G., Cyclotron—Induced Radiation Cataracts, Science, December 16, 1949, volume 110, pages 655–657.
(87) Uranium Hazards, Newsweek, 37: 49, April 30, 1951.
(88) Wolman, Abel, consultant, Atomic Energy Commission, Ionizing Radiation Materials as Air Pollutants, Archives of Industrial Hygiene and Occupational Medicine, August 1950, volume 2, No. 2, pages 134–136.
(89) Public Health Service Study of Hazards to Uranium Miners in Colorado Plateau Area, The Journal of the American Medical Association, volume 143, No. 10, page 903, July 8, 1950.
(90) Edson, E. F., Occuptional Radiation Hazards, British Medical Bulletin, vol. 7, Nos. 1–2, 1950, pp. 57–63.
(91) Browder, Frank N., Liquid Waste Disposal at Oak Ridge National Laboratory, August 31, 1950, United States Atomic Energy Commission.
(92) United States Department of Defense and United States Atomic Energy Commission, The Effects of Atomic Weapons, June 1950, United States Government Printing Office, Washington, D. C.
(93) Meinke, W. Wayne, Observations on Radioactive Snows at Ann Arbor, Mich., Science, May 11, 1951, pp. 545–546.
(94) A-Bombs May Fog Films, Science News Letter, May 19, 1951.
(95) Radioelements and Accessories, Eldorado Mining & Refining, Ltd., Post Office Box 379, Ottawa, Canada (1944).
(96) Industrial Uses of Radioactive Fission Products, Stanford Research Institute, September 1951, a report to the United States Atomic Energy Commission.
(97) Hempelmann, Louis H., Lisco, Hermann, and Hoffman, Joseph G., The Acute Radiation Syndrome: A Study of Nine Cases and A Review of the Problem, Annals of Internal Medicine, vol. 36, No. 2, February 1952.
(98) Robbins, Laurence L., Aub, Joseph C., Cope, Oliver, Cogan, David G., Langohr, John L., Cloud, R. W., and Merrill, Oliver E., Superficial "Burns" of Skin and Eyes From Scattered Cathode Rays, Radiology, January 1946, vol. 46, No. 1, pp. 1–23.
(99) Control of Radiation Hazards in the Atomic Energy Program, United States Atomic Energy Commission, July 1950, Superintendent of Documents, United States Government Printing Office, Washington 25, D. C.

The committee will stand in recess.

(Whereupon, at 12:30 p. m., the committee recessed, to reconvene at 2 p. m., of the same day.)

Reference for pages 521-23, 527, 532, 540

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

There will be a slight change in order of the witnesses by agreement. We will ask Dr. Western to be the first witness. Dr. Forrest Western of the Division of Biology and Medicine of the Atomic Energy Commission will be speaking on the subject of delayed fallout, the behavior in geological and physical processes and the mechanisms by which delayed fallout enters into the biological processes and reaches man.

Dr. Western, we are happy to have you with us.

at least, and I am sure this will add a great deal to our understanding of the importance of the different ones.

I believe we have one question here.

In the last paragraph in your discussion, in the comparison between radioactive particles being emitted within the body and outside of the body, there was no implication that strontium 90 is not associated with an increase of leukemia as well as bone cancer, was there?

Dr. WESTERN. That is a question which should properly be asked later. It was my intent to imply, as a matter of guidance, that the effect which I would expect from strontium 90 would be bone cancer. The probability of leukemia would be, relatively, sufficiently small to be of no concern. This is a question that should be asked of the biomedical experts.

Representative HOLIFIELD. Thank you very much, Dr. Western.

Our next witness will be Dr. Lyle Alexander from the Department of Agriculture. He will continue the discussion on delayed fallout and the behavior in geological and physical processes and the mechanisms by which delayed fallout enters into the biological processes and reaches man.

Dr. Alexander, we are happy to have you with us today. Will you proceed, please.

Reference for Pp. 521-23

STATEMENT OF DR. LYLE ALEXANDER, UNITED STATES DEPARTMENT OF AGRICULTURE [a]

Dr. ALEXANDER. Thank you, sir.

Representative HOLIFIELD. Are you making this presentation on behalf of yourself, Mr. Reitemeier, and Mr. Seymour?

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[a] Born at Athens, Tex., in December 1903. Received the B. S. degree from the University of Arkansas in 1928. That same summer he joined the U. S. Department of Agriculture (Bureau of Chemistry and Soils) as a junior soil physicist. He completed the Ph. D. (in chemistry) at the University of Maryland in 1935 while continuing laboratory research in the Department. Researches in soil science became increasingly broad and significant in both the laboratory and in the field. He was steadily advanced to research positions of greater responsibility. In 1938 he represented the Department at an important international conference on soil chemistry in Finland. After 1945 he had responsibility both for the basic soil research in the Division of Soils, Fertilizers, and Irrigation, and for the service and research laboratories of the Division of Soil Survey of the Bureau of Plant Industry, Soils, and Agricultural Engineering. He continued, however, highly significant personal research in soil science, including pioneer work on the use of radioactive isotopes. In 1951 he headed a successful international mission of scientists, under the auspices of the OEEC of the ECA, for the detailed study of laterite formation in the soils of Africa. His responsibilities for cooperative work with the Atomic Energy Commission increased. In 1950 he received the Superior Service Award from the Department.

Near the end of 1952, the Soil Survey was transferred to the Soil Conservation Service and he continued as Chief of the Soil Survey laboratories and as the Department's principal scientific liaison with the AEC. Except for broad project planning, others took over the details of the work on radioactive isotopes in what is now the Soil and Water Conservation Research Branch of ARS, while he gave increased attention to highly classified research for the Atomic Energy Commission. An important phase of this included researches dealing with the effects of radioactive fallout following bomb explosions, which have required many overseas study missions and field researches.

Besides these researches, he strengthened and reorganized the Soil Survey laboratories to serve the expanded soil survey program in the Soil Conservation Service. He has greatly improved the methods for measuring soil permeability and especially for interpreting the results. He is giving unusually valuable counsel to the leaders within the Service on all phases of soil chemistry and plant nutrition that relate to soil use and conservation. In 1954 he was advanced to his present position as soil scientist, GS-14.

Member and leader in many scientific societies, including the Sigma Xi, the American Chemical Society, the Soil Science Society of America, the American Society of Agronomy, of which he is a fellow, and the International Society of Soil Science, of which he is an officer. Vigorously applied his unusual gifts for sustained, arduous study—in the laboratory, in the field, and in the library—to highly difficult and complex scientific problems. He cooperates easily and effectively with other scientists in his own and related fields, and with nonscientists as well. He has an exceptionally deep sense of his responsibilities as a scientist, as a research administrator, and as a public servant. As a result, he not only carries along and finishes an enormous amount of work of the highest quality person-out. Dispersion is mainly by water movement, but also can be by transport in plankton, fish, or other organisms.

The depth in the ocean where the fallout particles occur has an important bearing on distribution. The water from the surface to the thermocline is often called the stirred layer, as it is assumed that this water is being mixed constantly. Below the thermocline, which occurs from 100 to 200 meters below the surface, the water is stratified and slow moving. Therefore, it may be assumed that small fallout particles will remain in the surface and may be transported great distances, whereas larger fallout particles will be moved horizontally while passing through the stirred layer, but relatively little once they are below the thermocline. Some support is given to this assumption by the fact that deep water samples from the vicinity of the Eniwetok test site just previous to the Redwing tests in 1956 were radioactive from previous fallout, which suggests that some radioactivity from earlier tests had not removed far horizontally.

Ultimately, the fallout in the surface water becomes a part of the major current system of the ocean and moves in a gyro around the entire basin. In the Northern Hemisphere the circulation is clockwise, and in the Southern Hemisphere counterclockwise. In the vicinity of the Eniwetok test site, the North Equatorial Current moves westward to the Philippines, where the current splits, with most of the water flowing northward to become the Japanese Current. Off the coast of Japan the current turns eastward to flow across the Pacific Ocean and arrives off the coast of North America at about 50° north latitude; there it flows southerly, and later westwardly, to complete the cycle.

In 1955, 1 year after Operation Castle, a survey was made to determine the distribution of radioactivity in the plankton and water of the North Equatorial Current in the western Pacific. Starting near the test site, the survey moved westward to the Philippines and thence northward to Japan. Activity, or other than from naturally occurring isotopes, was widespread and of low level, with the highest values found off the Philippines, a distance of 2,500 miles from the test site. Values for water ranged from zero to 537 disintegrations per minute per liter and for plankton from 3 to 140 disintegrations per minute per gram wet weight. As a comparison, the radioactivity in sea water from the naturally occurring isotope, potassium 40, is about 540 disintegrations per minute per liter. Although this fallout probably remained in the North Pacific circulation system, it would become increasingly difficult to detect because of the continuing processes of dilution and radioactive decay.

The radioactivity of water and plankton samples from an area contaminated by fallout, shortly after bomb tests, was determined on two series of Redwing samples. One series was collected during the operation and the other 6 weeks after its conclusion. During this period of time the maximum water value decreased to 16 percent and the plankton value to 2 percent of the earlier values.

The transport of radioactive isotopes away from a contaminated area by marine organisms is possible. One way this could happen would be for migrating fish to prey upon radioactive organisms while moving through a contaminated area. Another, and probably a more important way, is associated with the daily vertical migration of plankton. The diurnal migration of plankton to near the surface during hours of darkness and to deeper waters during hours of light is well known. There was evidence of this situation in samples collected near Bikini, just previous to Redwing. At the surface plankton was radioactive but the water was not, while in deep water both were radioactive. It is thought that this was a result of plankton becoming radioactive in the deep water and then moving toward the surface.

Marine organisms can acquire radioctive isotopes directly from the water in which they are living or indirectly by ingestion of other radioactive organisms. The acquisition of radioisotopes directly from the water may be either by absorption or adsorption, but this is of little importance from the point of view of the food chain. An example of a food chain leading to man starts with the one-celled plants, then leads to the one-celled animals, to the small many-celled animals, to small fish, to large fish, such as a tuna, and finally to man. There may be a few, or there may be many links in the food chain, and radiosotopes may enter the chain at any point.

Marine organisms, similar to terrestrial plants and animals, differentially select and retain minerals in their bodies, and can concentrate elements from sea water. The selection of an element depends upon the physiological demand of the organism for the element and the availability of the element, and to some extent, of chemically similar elements. The greatest concentration will occur when the demand and availability are greatest, and vice versa. For example, because zinc is relatively scarce in sea water and there is a physiological demand for this element by fish and shellfish, zinc in an available form that is added to sea water is rapidly removed and concentrated by fish and shellfish. A similar example is that of the alga, *Asparagopsis*, for iodine. On the other hand, when strontium, which is naturally more abundant in sea water, is added to sea water, its concentration by most marine organisms is not great.

The plankton samples collected during and after the Redwing operation were analyzed for the radiosotope composition. The isotopes found include strontium 89 and 90; barium 137 and 140; cerium 144; praseodymium 144; ruthenium 103 and 106; zirconium 95; cobalt 57, 58, and 60; zinc 65; iron 59; and trivalent rare earths. There were differences in the isotopes found in the plankton samples collected in different areas. One reason for this difference is that plankton is composed of many groups of organisms, each with an affinity for specific isotopes.

For this same reason, the concentration factor of radioactivity by plankton in relation to the water of its environment varies greatly. A concentration factor of a thousand or greater is often observed. Because plankton does concentrate fission products and other radioisotopes, measurement of the radioactivity in a plankton sample is a convenient method of determining the presence of radioactive isotopes in the water.

In fish most of the elements expected from fission are found and also the nonfission products formed by neutron irradiation of bomb and tower metals, manganese 54, iron 59, cobalt 58 and 60, and zinc 65. Often the nonfission products predominate. It has been mentioned that little strontium is found in most marine organisms. A land crab does accumulate strontium 90 in the liver and shell, whereas marine crabs contain little strontium 90.

A program of radiobiological monitoring has been a part of all test series in the Pacific Ocean. Samples of fish, invertebrates, birds, plankton, water, soil, algae, and terrestrial plants and animals have been collected from the ocean, lagoon, reef, and islands of many places in the Pacific Ocean. Some have been visited only once, while others many times. Except for the immediate vicinity of the test site, biological contamination by fallout in the Pacific Ocean has been very slight.

Representative HOLIFIELD. Thank you very much, Dr. Alexander. That was quite a task for you to go through that, particularly at the speed that you went through it. But I think you have given us a lot of very valuable information for our record, and we appreciate it.

Our next wtiness is Dr. Roger Revelle, Scripps Institute of Oceanography, University of California.

As a fellow Californian, sir, I welcome you to the witness stand.

Reference for pp 527, 532 & 540

STATEMENT OF DR. ROGER REVELLE, DIRECTOR, SCRIPPS INSTITUTE OF OCEANOGRAPHY [3]

Dr. REVELLE. Thank you, Mr. Holifield. I have some charts that we might put up.

Representative HOLIFIELD. Very well.

Dr. REVELLE. I have a prepared statement which I would like to submit for the record.

Representative HOLIFIELD. Without objection, your prepared statement will be received for the record, and you may proceed to summarize in any way you desire.

(The statement referred to follows:)

STATEMENT BY PROF. ROGER REVELLE, SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA

1. At present the measurable radioactivity in the oceans consists of the natural radioactive elements and artificial radioisotopes from tests of atomic weapons.

2. In the future, additional radioactivity may become introduced into the ocean from the use of atomic weapons, accidents to nuclear powered vessels, accidents to nearshore reactors, from the oceanic disposal of atomic waste, and in coastal areas, from land runoff. Some evidence that this latter effect now exists in the La Jolla region is shown on table 1.

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[3] Scripps Institution of Oceanography. Date and place of birth: March 7, 1909, Seattle, Wash. Education: A. B., Pomona College in 1929; Ph. D. in oceanography, University of California in 1936. With the exception of service in the Navy during and immediately after World War II, his entire career has been spent at the University of California's Scripps Institution of Oceanography, of which he became director July 1, 1951. On staff of Adm. W. H. P. Blandy in Operations Crossroads in charge of oceanographic measurements. Organized resurvey of Bikini in 1947. Fellow of American Association for Advancement of Science, San Diego Society of Natural History, Geological Society of America; member, American Meteorological Society, Sigma Xi, Society of Limnology and Oceanography, Geological Society of Washington, Western Society of Naturalists, Cosmos Club, Men's Faculty Club, Berkeley, American Association of Petroleum Geologists, and American Geophysical Union. President for 1956–59 of the section on oceanography of the American Geophysical Union. President of special committee on oceanographic research of International Council of Scientific Unions; chairman, National Academy of Sciences Committee on Biological Effects of Atomic Radiation in Oceanography and Fisheries; member for North America of International Advisory Committee on Marine Sciences of UNESCO; member, Committee for the International Geophysical Year of the International Association of Physical Oceanography; the Panel on Oceanography of the National Committee for the International Geophysical Year; and Divisional Committee for Mathematical, Physical, and Engineering Sciences of National Science Foundation. In 1954, Dr. Revelle received the Albatross Medal of Swedish Royal Society of Science and Letters for outstanding achievements on oceanography, especially in deep-sea research. Honorary doctor of science from Pomona College. Elected to National Academy of Sciences April 23, 1957. (Submitted by witness.)

...es. If, owing to a collision, the reactor is lost in a harbor, say 8 miles long ...3 miles wide by 50 feet depth, and the fission products become uniformly ...stributed, the water in the harbor would contain 10^{-2} curies per cubic meter ...ving an almost constant radiation dose of about .5 r per day on the surface. ...ck pilings, ship bottoms, and other structures covered with fouling organisms ...uld accumulate a much higher level of radioactivity, and, of course, local ...centration in the water may be extremely high.

...1. Food habits of different nations must be taken into account in evaluating ...e hazards to human beings from fallout over the oceans. This is particularly ...e in the case of the Japanese, who obtain about one-third of their calcium ...m marine fisheries. Table 10 shows the sources of calcium in the Japanese ...et.

To accomodate these differences we must investigate the differences between ...e terrestrial and marine uptake problems for specific isotopes. For example, ...ning specifically to the strontium 90 problem we have made a comparison ...tween the strontium 90 that will be obtained from land-derived and ocean-...rived foods in table 7.

Three factors enter into this: (1) The much higher concentration of calcium ...n soils than in sea water, (2) a dissemination of strontium 90 from fallout ...n a much greater volume of water in the ocean than soil on land, and (3) the ...ifferent amount of discrimination against strontium in fish than, for example, ...n milk cows.

22. Although maximum permissible concentration has been established for ...ost radioactive substances, recent evidence indicates that much smaller ...mounts of radioactivities do produce physiological effects, for example leu-...emia.

23. Introduction of radioactive substances in the ocean has beneficial as well as harmful effects in so far as it enables us to use tracer techniques in the study of the movement of the water and the life cycles and metabolism of marine organisms. As an example figure 1 indicates the intrusion of a clean water mass along the level of high stability and the persistence of deep activity around Bikini Atoll 2 years after an event.

TABLE 1.—*Apparent effect of runoff on activity of nearshore ocean water—Samples of suspended sediment* [1]

Date of collection 1957	Preceding weather	Activity [2]		
		Zr, Nb	Ru, Rh	K [40]
April 12–22	Calm, dry	5,000	1,200	900
April 22–May 5	do	2,000	900	900
May 5–16	Calm, rain	11,000	4,000	900
May 16–20	Heavy swell, intense rain	22,000	2,300	900

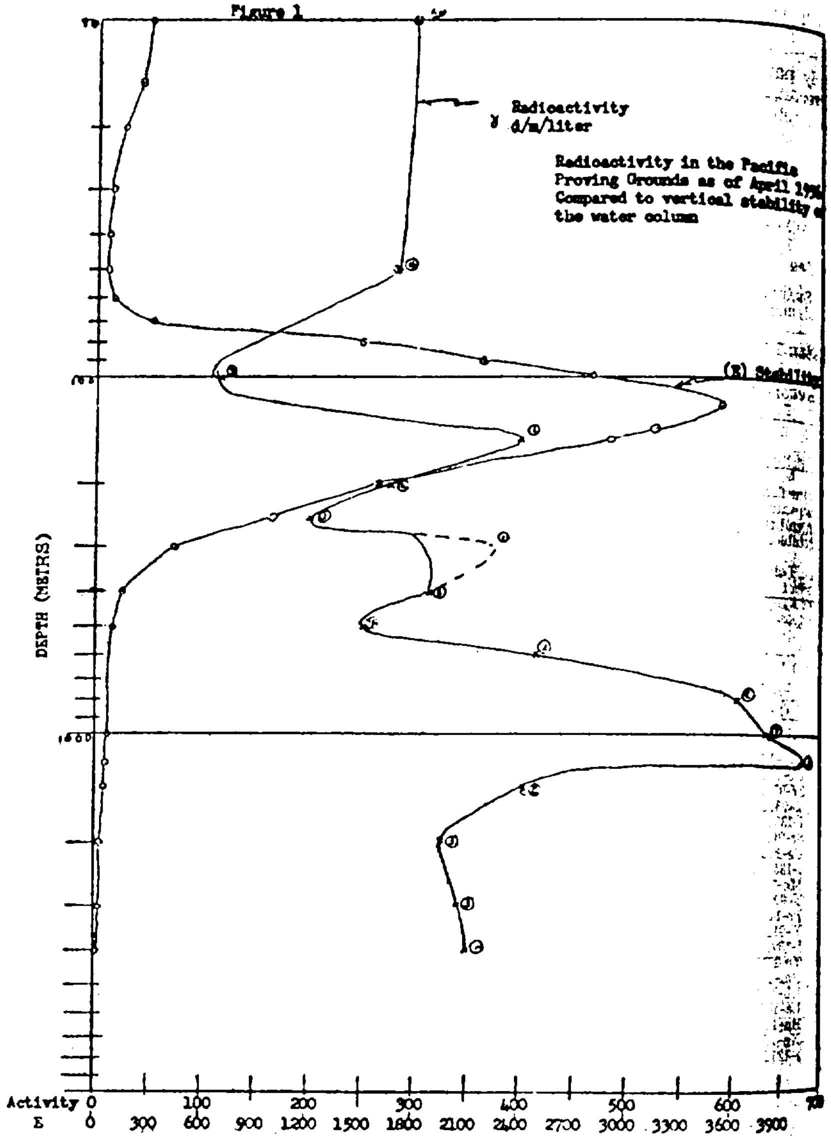
[1] Collected by filtering water from about 300 meters offshore at La Jolla where the sediment concentration is 10–30 p. p. m. of the seawater (*from unpublished data T. R. Folsom*).
[2] Gammas minute/kilogram of sediment determined by gamma spectrometer.

TABLE 2.—*Radioactivity of sea water*

Nuclide	Concentration (g cm.$^{-3}$)	Specific activity—Number of of disintegrations (cm.$^{-3}$ sec.$^{-1}$)	Total amount in ocean (megatons)	Total activity in ocean (megacuries)	Energy of γ radiation (MEV.)
[illegible]	4.5×10^{-8}	1.2×10^{-3}	63,000	460,000	[a] 1.5
[illegible]	8.4×10^{-8}	2.2×10^{-4}	118,000	8,400	No. γ
[illegible]	2.0×10^{-9}	[b] 1×10^{-4}	2,800	3,800	.05–.82
[illegible]	1.5×10^{-11}	[b] 3×10^{-6}	21	110	.06–.18
Th^{232}	10^{-11}	[b] 2×10^{-7}	14	8	.03–.08
Ra^{226}	8.0×10^{-16}	[b] 3×10^{-5}	4.2×10^{-4}	1,100	.18–.60
[illegible]	4×10^{-17}	7×10^{-6}	5.6×10^{-6}	270	No γ
[illegible]	8×10^{-20}	2.5×10^{-5}	1.5×10^{-6}	12	No γ

[a] γ/β = 1.1.
[b] Activity of nuclide+daughter products.
[c] Only in top 50–100 meters of the ocean.

Figure 1



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...ch bothers us, as I will point out in a minute, is that the marine ...ganisms concentrate radioactivity by a very large factor.

I might also point out that the marine organisms, unlike the waters, ...ve fairly rapidly. Many of them conduct a vertical migration ...ween day and night over a depth of 1,000 or 2,000 feet. They move ...to the surface in the night and down to a depth of several hundred ...feet during the day. Many of the fish we are interested in, such ...as tuna, marlin, sailfish, bonito, skipjack, and salmon, migrate over ...very large horizontal distances. This is also true of the marine mam...mals such as the whales.

Representative HOLIFIELD. Do they feed on any of the marine life ...that moves vertically up and down?

Dr. REVELLE. Yes, sir, they do indeed; particularly the whalebone ...whales, and the tunas feed almost exclusively on these smaller organ...isms which do migrate over depths that I have mentioned.

Representative HOLIFIELD. What are the natures of some of the ...small organisms? You are not referring to plankton?

Dr. REVELLE. I am referring to zooplankton and other invertebrates ...which swim, such as the squid. In tropical regions of the Pacific very ...large tuna are obtained by the Japanese at considerable depths below ...the surface during the daytime and presumably the big tunas are ...down there, because that is where their food supply is, although this ...is not very well known, either. I do not want you to get me wrong. ...We really know very little about the ocean. Everything I say is sub...ject to a good deal of uncertainty.

Representative HOLIFIELD. That is spoken like a true scientist. I ...think any scientist who testifies before us disclaims any knowledge ...whatever of the subject upon which he is *testifying*. We take that ...as modesty and we would rather have you that way than the other ...way.

Dr. REVELLE. As a matter of fact, in my case it is not modesty. It ...is just a simple statement of fact. Oceanographers are masters of not ...knowing very much about what they are doing. One of the things ...that is very often said, and I think with complete justification, is that ...we know less about the bottom of the ocean than we do about the surface ...of the moon.

Although the ocean has almost every substance in it, many of these ...substances, as I pointed out a minute ago, are present in very low ...concentration. Hence in order to live marine organisms have to con...centrate the substances they need for their growth from sea water. ...Often they concentrate such substances—these trace substances—by ...factors of many thousand times. This necessity for concentrating ...trace substances from sea water means that the marine organisms are ...especially adapted for doing this job, and it means they will concen...trate other substances present in small concentrations, such as arti...ficially radioactive substances originating from fallout, or in other ...ways also by factors of many hundreds to many thousand of times.

What is the significance of these generalities? I have stated nearly ...everything I can in my prepared statement, but perhaps we might ...summarize some aspects of this problem of the significance. Coming ...first to the close-in fallout, even several months after a major weapons ...test there is a relatively high level of fallout within 500 to 1,000 ...miles of the test site for a period of at least a few months. This ...depends, in the case of the Marshall Islands area, on the sluggish nature of the motion of the water. Here I have shown on this the surface currents in the neighborhood of Bikini Atoll. H Bikini. Here is Eniwetok. Kwajalein gives you some idea scale of the chart. The green lines show the surface current an red lines currents at a depth of about 1,000 feet.

We see that the surface currents are somewhat disturbed by t istence of the atolls. But in general we have a motion from e west of the order of half a mile per hour, or about 12 miles per At a depth of about a thousand feet, there is a very much obvious effect of the existence of the islands. We see a great ed the neighborhood of Bikini Atoll. The water, instead of moving the atoll, tends to stay in this area right around the atoll for a considerable length of time.

As a result of this difference in the circulation near the surfa at depth, a graph in my statement shows that in fact after 2 year concentration of radioactive substances in the neighborhood of Bi is much higher at depth than at the surface by a factor of 2 or 3, quite low, however, at all depths. That is 2 years after a test.

Representative HOLIFIELD. Is that strong enough to affect th bility of the fish in that area?

Dr. REVELLE. Yes, sir, it certainly is, as I will show you in few minutes. I simply want to point out here the relatively sl motion of the currents, which means that the fallout tends to s this general area, but is diffused laterally and as I pointed out, cally in the top 100 meters.

I am sorry the next chart is on such a small scale, but these w left with you. This small scale has the great advantage that it how big the ocean is. This is the water hemisphere covering about half the earth—the Pacific Ocean. In this area in here th Bikini, here is Japan, the Philippines, New Guinea, Australia, Un States, and South America. This area of 1,000 miles around Bi was carefully investigated by Japanese oceanographers and biolo 4 months after the Castle test. They got figures like this in the w 23,000, 90,000, 79,000, 26,000 disintegrations per minute per lit sea water. The values that we are talking about here are valu the order of one one-hundredth to three one-hundredths of a m curie per liter of water 4 months after a test. The distribution quite spotty as we go along this time. (See folding chart, p. 551.)

I will read some numbers—5,100, 90,000, 14,000, 16,000, 2 and 16,500. This is at a distance of about 300 miles.

Representative HOLIFIELD. Is that measurement of quantitie sea water?

Dr. REVELLE. Those are disintegrations per minute of radioac material.

Representative HOLIFIELD. In a certain amount of sea water.

Dr. REVELLE. In a quart of sea water. This is about 300 miles of Bikini Atoll. When we go a thousand miles west of Bikini, w much smaller values. The biggest one here is about 4,500 disinte tions per minute per liter.

Representative HOLIFIELD. What is the natural disintegration p minute per liter?

Dr. REVELLE. In the water itself, due to the natural radioactivi if we are talking about gamma radiation, it is about 50 disintegrati

Reference for pages
-777

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

WEDNESDAY, MAY 29, 1957

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION
OF THE JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C.

The special subcommittee met, pursuant to recess, at 10:10 a. m., in the caucus room, Senate Office Building, Hon. Chet Holifield, chairman of the subcommittee, presiding.

Present: Representatives Holifield, Durham (chairman of the joint committee), Price, Van Zandt; Senators Anderson, Knowland, Hickenlooper, and Bricker.

Also present: Professional staff members: James T. Ramey, executive director; George E. Brown, Jr., Hal Hollister, staff technical adviser, and Paul C. Tompkins, consultant.

Representative HOLIFIELD. The subcommittee will be in order.

This morning we have a notable array of witnesses. We have several witnesses, and we plan to add on additional witnesses from the Walter Reed Institute of Research to our list of this morning, provided the time allows. But before we call the first witness to the chair, I intend to make a short statement.

This committee and its chairman, under the direction of the committee, is trying to hold an objective and fair hearing. We are trying to bring to this record scientific opinion on the different facets of nuclear weapon fallout, and of the scientific problems that are pertinent thereto.

There will, of necessity, be controversial opinions stated; and this is as it should be in the scientific world, because different scientists on their own responsibility and integrity certainly have a right to be heard.

We do not want to get into the field of controversy with anyone as a committee, but there was called to my attention this morning a release by the Atomic Energy Commission in regard to this question of a clean or dirty bomb.

In the first place, the Atomic Energy Commission violated its own rules by not preparing and submitting to the committee its release 24 hours in advance of its release. We do not intend to get into this question at this time, and into a controversy with the Commission, but the record will stand as it has been given; the remarks of Dr. Graves will stand as those of the man most qualified to give an opinion on the cleanness or the dirtiness of nuclear weapons, and at the proper time there will be other evidence brought forward on this subject.

)0 micromicrocuries per gram
discrimination factor of
actor of 8—but I think you
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 the population of Britain
ram of calcium indefinitely
lmost our maximum level of

to allow for nonhomogeneity
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he average on the basis of
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ld it take to achieve that?
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 crucial biological point,
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s a threshold, we have to

...k at this (100 micromicrocuries) as the maximum permissible level. ...it is a nonthreshold response we may look at this as an average ...and try to decide what the risk is averaged over the entire popu-...ion or averaged over any segment of the population.

What a nonthreshold response essentially says is that for every ...rement increase in dose there is an equal increment increase in ...t and theoretically there is no maximum permissible level. There ...n extremely small probability that any amount of radiation, the ...unt we wear on our wristwatches or the amount that we get from ...natural potassium is going to harm somebody.

So the whole point of which of these numbers we can accept will de-...d upon our making a value judgment how much is atomic energy ...th in cases of leukemia and bone cancer on a probability basis, ...raged over the entire population or a certain segment thereof.

Senator ANDERSON. Thank you very much. I can say from personal ...uaintance I know how long and hard you have worked in this field ...d I am very grateful to you for your testimony.

The next witness is Dr. Anderson.

Dr. ANDERSON. Mr. Chairman, I have nothing to add to the formal ...atement Dr. Langham made. I was in attendance only to answer ...stions.

Senator ANDERSON. Before we proceed with a discussion period with ...r several witnesses, there are several things that I would like to ...sert in the record at this point. First a statement by Wright H. ...ngham and Ernest C. Anderson. Next an article from Science Magazine, by Ernest C. Anderson, Robert L. Schuch, William R. ...sher, and Wright Langham, and finally a statement by L. D. Mari-...lli and J. E. Rose of the Argonne National Laboratory.

Reference for pp 764-65, 766 & 769

(The material referred to follows:)

SR-90 AND CS-137 IN RELATION TO THE PROBLEM OF WORLDWIDE RADIOACTIVE FALLOUT

By Wright H. Langham and Ernest C. Anderson, Los Alamos Scientific Laboratory, University of California, Los Alamos, N. Mex.

Although a number of isotopes are present in the fission mixture, the fallout of Sr-90 from weapons testing programs is the principal concern. Sr-90 is the most ...portant isotope because of its similarity to calcium, long physical and biological ...lf-time and high relative fission yield. These factors lead to high incorporation ...the biosphere and a long residence time in bone. General contamination will ...sult in the bones eventually reaching an equilibrium state with the Sr-90 ...the biosphere.

Accepting Libby's postulation of three types of fallout (local, tropospheric, and stratospheric), levels as of the fall of 1956 were about 25 mc./mi.[2] for the upper ...dwestern and northeastern sections of the United States, 16 mc./mi.[2] for the ...tion between 50° N. and 10° S. latitude, and about 4 mc./mi.[2] for the rest of ...e world. These general values are variable, depending upon local rainfall ...d other meteorological patterns.

The observed levels of Sr-90 in bones of various ages are in good agreement ...th those calculated on the basis of a simple model of skeletal growth, re-...odeling and exchange. Using the data of Kulp for adults and children normal-...ed to this model, an average equilibrium value of 3 μc. Sr-90/g. Ca is calculated ...r about 1975. Estimation of the equilibrium value from ecological discrimina-...n factors suggests approximately the same average level. The normal spread ...values for stable strontium and Sr-90 in human bones and for Cs-137 in people ...ggests that there is a very low probability that many people will show levels ...re than three times the average. On the basis of an equilibrium concentra-...n of 3 μc. Sr-90/g. Ca resulting from detonations to date, about 18,000 mega-...s of fission could be injected at once into the biosphere before the average value would equal the maximum permissible level of 1,000 μc./g. Ca (the MPL for

Reference pp 765, 766 & 769

24. $\tau = 1/\lambda = t^{1/2}/0.693$, where τ is the mean or average time the nuclide remains in the body, λ is the elimination rate, and $t^{1/2}$ is the time necessary to remove half the body burden.

STATEMENT SUBMITTED TO THE JOINT COMMITTEE ON ATOMIC ENERGY BY L. D. MARINELLI[1] AND J. E. ROSE,[2] RADIOLOGICAL PHYSICS DIVISION, ARGONNE NATIONAL LABORATORY, LEMONT, ILL.

TOPIC IX. OCCURRENCE OF CS-137 IN THE ATMOSPHERE, BIOSPHERE, AND ITS UPTAKE AND BEHAVIOR IN MAN

The fission product Cs-137 is produced with a yield of about 6 percent and it has a half life of about 27 years. The general characteristics of its distribution and behavior in mammals, as reported by several authors (1-4), indicates only a partial qualitative similarity to potassium. Important from our standpoint is the fact that cesium is excreted by humans at a rate lower than potassium. This leads to a Cs/K ratio in vivo which is from 2 to 3 times the ratio in the ingested food.

Because of its gamma-ray emission, Cs-137 can be measured in the living animal and in bulk material without recourse to lengthy chemical analysis.

To make these measurements, it is necessary to shield both instrument and subject from the radiation emitted by ordinary building materials. This is done by performing the tests in an 8 by 8 by 6 foot room with 8-inch steel walls, weighing 60 tons. This room consists of a bolted frame of angle beams upon which one-quarter inch plates of 12 to 26 inches width are placed in staggered sequence on all sides in order to avoid continuous cracks in the walls. The side plates are held in place by clamping them together between the frame and appropriately placed angle irons.

Gamma-ray radiation emitted by the subject impinges on an 8 inch by 4 inch NaI crystal; the electrons liberated therein produce scintillations which are amplified by a photomultiplier tube and registered, according to their sizes, by a 256-channel analyzer. From the scintillation spectrum it is possible to identify the energy of the gamma radiation (hence the radioelement responsible for it) an dits intensity (hence the amount of material involved). Presently this apparatus has a sensitivity greater than 10^{-9} curies of the gamma emitters under discussion in the intact human subject.

In the summer of 1955, at the Argonne National Laboratory, measurements of the total body gamma-ray activity of members of our staff, visitors from various parts of the country and from overseas, local medical students, etc. (5), disclosed the presence of this radioelement in all of the test subjects. Since then, continued tests on a group of 12 people, has shown an increase in the human burden by a factor of about 2 up to the spring of 1956, and a constant value thereafter, corresponding to about 3.2×10^{-11}C of Cs-137 per gram of potassium (fig. 1). Contrasted to the findings for Sr-90, children do not exhibit high concentration per unit weight.

No correlation between Cs-137 content and geographic origin of the subjects was noted (*table I*). *On the other hand, the dependence on the* dietary habits of the individual (fig. 2) became evident after a study of the Cs-137 content of food and water. These revealed that bovine meats, milk and milk products constitute the main routes of intake (fig. 3). Subsequent confirmation of these findings on larger representative samples of people and foodstuffs have been obtained at the Los Alamos Scientific Laboratory (6). The observations to date

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[1] 9017 South Leavitt, Chicago, Ill.; home phone, Beverly 8-1207; office phone, Lemont, Ill., 800. Date and place of birth: November 28, 1906, Buenos Aires, Argentina. Education: bachelor of science, Cooper Union, 1931; master of arts, Columbia, 1936. Work history: Meter tester, Consolidated Edison Company of New York, 1927-29; radium technician, New York Memorial Hospital, 1929-35; assistant physicist, 1935-43; physicist, 1943-48; Sloan-Kettering Institute, 1947-48; Senior Biophysicist and Associate Director, Division of Radiological Physics, Argonne National Laboratory, 1948—; Division of Biological Medical Research, 1950—. (Submitted by the Atomic Energy Commission.)

[2] Date and place of birth: August 21, 1904, Wilkinsburg, Pa. Education: Carnegie Institute of Technology. Work history: Standard Chemical Co. (radium); Tumor Institute of the Swedish Hospital, Seatle, Wash. (early pioneering work in supervoltage X-ray equipment); National Cancer Institute, Bethesda, Md.; Metallurgical Laboratory, University of Chicago; since 1944 Director of the Radiological Physics Division of Argonne National Laboratory. Member of American Physical Society, Fellow of the American Association for the Advancement of Science, Fellow of the American College of Radiology, honorary Sc. D. (Submitted by witness.)

are consistent with the concepts of (*a*) stratospheric storage, (*b*) *constant* deposition on grazing lands, (*c*) uptake by cattle, and (*d*) transmittal to man. Other relatively abundant and long-lived fission products, i. e., Ce-144—Pr-144 (… day), Zr-45—Nb-95 (63.3 day), and Ru-106—Rh-106 (1 year), easily detectable by our *technique* in laboratory air, dust, sweepings from house carpets (… 4) and soil (7) are not present in the intact mammal in measurable quantities. These findings are consistent with previous observations on their low intestinal absorption following oral intake by laboratory animals (3).

In its present concentration, Cs-137 contributes on the average less than 0.3 … to the yearly dose of over 150 mrads which a human being is reported to … from natural sources of *radiation* (fig. 1).

Because of its relatively *short life* in the cow and of its reputed unavailability … the roots of *some plants*,[8] the concentration of this radioelement in milk is likely to serve as an excellent indicator of average rate of fallout over milk sheds. Since we can measure directly its presence in the living human we need not rely on theoretical predictions as to the possible individual variations *under* various conditions. Thus, only a factor of 6 separates the lowest values found in oriental subjects (whose diets are practically devoid *of cattle* products) to the highest found in the United States of America *in an* individual on a milk diet.

Pertinent to this discussion *and to* item X of the agenda are our recent findings on some inhabitants *of the* Marshall Islands which were measured in our facility by *Dr.* C. E. Miller. The scintillation spectra are shown in figure 5, and the *body* contents are included in table I. It should be noted that *subject* No. *10* is a control living in Majuro Island which did not *experience unusual* fallout. The next four subjects were inhabitants of Rongelap *removed* more or less permanently from that island to Majuro Island because of heavy fallout. Their content of Cs-137 is about 2 or 3 *times* that of the average United States citizen. The reason for this cannot be stated at this time but consumption of coconuts (reputed to acquire Cs) may be implied. The presence of Zn-65 in their body is due *to contamination* of seafood.

The highest contents of both Cs-137 and Zn-65 were found in subjects Nos. 5 and 18 who were removed temporarily from the island of Uterek *because* of heavy fallout and returned there after appropriate decay *of the* external radiation. It is obvious that they represent burdens *likely* to be acquired by living in zones of relatively high levels of *contamination.* Yet, despite these circumstances the increased dose rate *of radiation* to which they are exposed is only a fraction of the normal background of 100 to 160 mrads per year.

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(NOTE.—See middle of p. 745 for a remark concerning this statement.)

TABLE I.—*Gamma ray activity of human beings*

Country	Subject	Date	Cesium 137			Zinc 65		Natural Potassium
			μμc/gK	mμc/man	mrads/yr.	mμc/man	mrads/yr.	mrads/yr.
United States	Average	1956	34.0	4.8	0.29			Average value for all humans [illegible]
England	T	May 16, 1956	33.0	4.7	.28			
Do	R	July 18, 1956	35.0	4.9	.29			
France	J	Sept. 21, 1956	33.0	4.6	.27			
Denmark	F	Oct. 30, 1956	26.0	3.7	.22			
Sweden	N	Nov. 29, 1956	32.0	4.5	.27			
Australia	P	Mar. 27, 1957	50.0	7.0	.42			
India	Vo	Dec. 18, 1957	18.9	2.6	.16			
Do	Va	do	20.8	2.9	.17			
Japan	S	July 26, 1956	24.5	3.4	.20	3.2	0.02	
Indonesia	S	Aug. 10, 1956	13.9	2.0	.12	2.1	.01	
Do	M	do	8.5	1.2	.07			
Marshall Islands	10	Apr. 5, 1957	65.0	9.1	.55	30.0	.19	
	6	do	69.0	9.7	.58	73.0	.46	
	9	do	73.0	10.0	.61	30.0	.19	
	4	do	79.0	11.0	.67	30.0	.19	
	7	do	95.0	13.0	.80	62.0	.39	
	5	do	1,600.0	230.0	14.0	480.0	3.0	
	8	do	2,700.0	380.0	23.0	230.0	1.5	

Source: NBS Handbook 52—Maximum Permissible Levels: Zn-65 = 430 μcs; Cs-137=90 μcs.

FIGURE 1

Cs^{137} TRENDS IN HUMANS

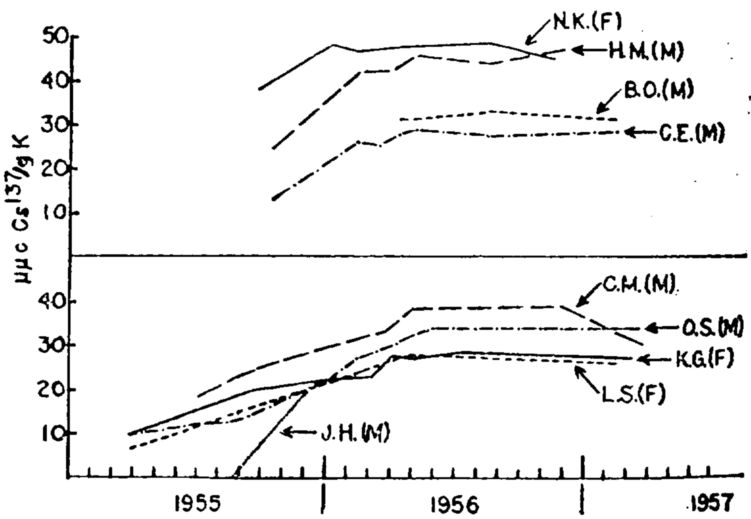
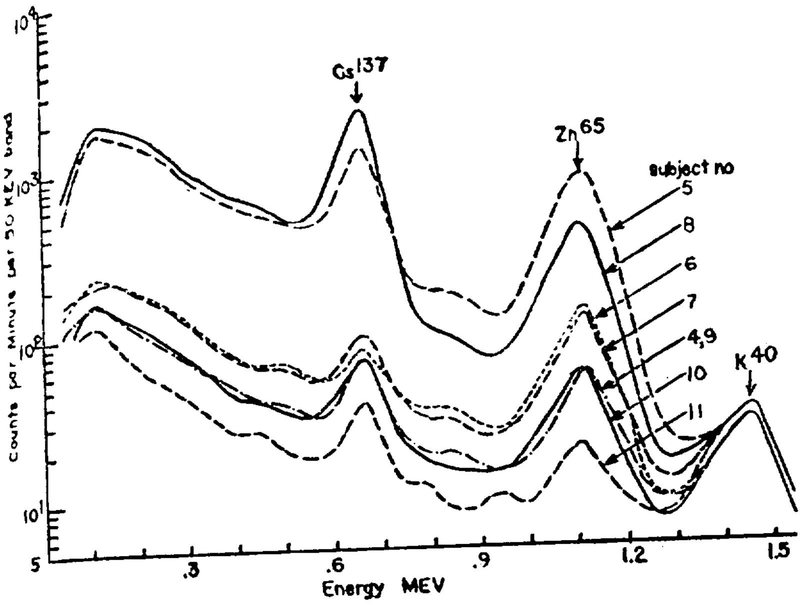


FIGURE 5

NET in vivo GAMMA RAY SPECTRA OF MARSHALLESE



Senator ANDERSON. Dr. Kulp, Dr. Eisenbud, and Dr. Neuman, do you and Colonel Hartgering want to get into some questions here, back and forth, that would be helpful to all of us? Dr. Langham, we would like to have you in it also.

Mr. Neuman, do you want to kick off on any comments you may have on the afternoon presentation?

DISCUSSION BY DR. J. L. KULP, MERRIL EISENBUD, DR. WILLIAM F. NEUMAN, DR. WRIGHT LANGHAM, AND COL. JAMES B. HARTGERING

Dr. NEUMAN. I would rather sandbag, if I may.

Mr. RAMEY. It might be desirable if Dr. Neuman could sort of state his case. Some of the members were not here and Dr. Kulp was not here at the time either.

Dr. NEUMAN. As a brief summary, I think it best to say that, in my opinion, the very best evaluation of future levels of bone are those calculated from our equilibrium data on natural strontium because this involves only one assumption; strontium behaves like strontium.

It is also my opinion that the natural strontium data in England and the bulk of the experimental data available in this country indicate that the overall discrimination from ground to bone is about a factor of 8. With this number, one has a fixed relationship between ground level and bone level. If we choose a certain maximum level to be permitted in human bone, we automatically fix a maximum level that can be permitted on the ground. With this number one can calculate the maximum rate at which testing can produce fission

Reference for pp 777-10008

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

MONDAY, JUNE 3, 1957

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION
OF THE JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C.

The special subcommittee met, pursuant to recess, at 10:10 a. m., in the caucus room, Senate Office Building, Hon. Chet Holifield, chairman of the subcommittee presiding.

Present: Representatives Holifield, Durham (chairman of the Joint Committee), Price, Dempsey, Van Zandt; Senators Anderson, Hickenlooper, and Bricker.

Also present: Professional staff members: James T. Ramey, executive director; George E. Brown, Jr., Hal Hollister, staff technical adviser, and Paul C. Tompkins, consultant.

Representative HOLIFIELD. The committee will be in order, please. The hearings have covered up to now sections I through IX of the outline. This includes background information on the nature of radioactivity, the production of fallout by the detonation of weapons, its transport in the atmosphere, and its deposition and uptake in animals and man. We spent a good deal of time on local and delayed fallout and began our investigation of the main culprit, strontium 90. Many subjects that initially appeared to represent marked disagreement have developed into subjects on which there is general agreement when put into perspective.

(*a*) The radioactivity from fission products is considerably more dangerous than the radioactivity induced in the environment by neutrons. Furthermore, a radioactivity "clean" weapon device is apparently not possible.

(*b*) The way radioactive materials are introduced into the biosphere is subject to wide variation with air detonations favoring wide dispersion and surface detonations favoring local fallout. For estimating how much material is injected into the stratosphere the consensus figure is about 50 percent, although RAND and others feel that 20 percent is a better figure for detonations over land. The distribution of worldwide fallout appears to be nonuniform. Variation from the average by more than threefold, as far as long-range deposition is concerned, does not appear to happen.

(*c*) The depositions from fallout to date in the biosphere including uptake in man is apparently low—approximately 10 percent—when compared to natural radioactivity. The significance of this fact has yet to be discussed.

Date and place of meeting	Members present	Officers
1928, Stockholm	5	G. W. C. Kaye (United Kingdom), Chairman,
1931, Paris	7	Do.
1934, Zurich	7	Do.
1937, Chicago	7	Do.
1950, London	10	E. Rock-Carling (United Kingdom), Chairman, Taylor (United States), Secretary.
1953, Copenhagen	11	E. Rock-Carling (United Kingdom), Chairman, W. (United Kingdom), Secretary.
1956, Geneva	[1] 12	Do.

[1] Main Commission only. Subcommittee membership totaled approximately 50; a substantial n[illegible] of these were in attendance.

The Eighth International Congress of Radiology is scheduled to mee[illegible] Munich in 1959. The next formal meeting of the ICRP has not been sched[illegible] and may be held prior to the Congress. For the period 1956–59, the officers [illegible] the main Commission are R. Sievert (Sweden), Chairman; G. Failla (Unit[illegible] States), Vice Chairman; W. Binks (United Kingdom), Secretary.

(Mr. Taylor's statement—continued.)

The National Committee on Radiation Protection and Measurements beginning in 1929 has done the same for the United States on a continuing basis.

EXHIBIT 14. NCRP HISTORY

1929–46

1. FORMATION

The roots of the National Committee on Radiation Protection and Measurements go back to 1928 and are intimately related to the formation of the International Commission on Radiological Protection in July of that year. With the possibility in mind of forming an international organization on radiological protection, the Second International Congress of Radiology, before meeting in Stockholm in July 1928, invited several countries to send representatives to the Congress for the purpose of discussing protection problems and possibly preparing some initial X-ray protection recommendations. From the United States, L. S. Taylor was designated as representative of the National Bureau of Standards, and one representative each attended for the American Roentgen Ray Society and the Radiological Society of North America.

When attempts were made to reach agreement between the United States and other countries, serious difficulties arose. Each of our two radiological societies offered different recommendations and each claimed to be the authoritative body. The NBS had no recommendations to offer and was there more by way of an observer. As a result, the recommendations that were in fairly acceptable form, prepared by the British protection committee, were adopted as the first international recommendations. In the process, the United States delegates showed up rather poorly in that agreement could not be reached on who authoritatively represented the views of the United States.

Germany presented a somewhat similar though not quite so serious a situation as had the United States, in that its representatives at the preliminary discussions also could not agree on who carried the necessary authority.

Concurrent with the meetings of the Congress, G. W. C. Kaye and Stanley Melville (Great Britain) and L. S. Taylor (United States) set about to organize a permanent structure for an international organization. After preliminary discussions, during which some general rules of organization were developed, the International Commission on Radiological Protection[1] was organized, the membership consisting of the above-mentioned persons, Dr. Rolf Sievert of Sweden and Dr. Gustav Grossman of Germany. It was agreed by this group that the Commission should be kept small, and that wherever possible, representatives to the Commission should be chosen from national laboratories where such laboratories existed in member countries. This arrangement and the general philosophy of operation of the Commission was approved by the Second International Congress of Radiology before the close of its sessions.

[1] Until 1946, the Commission was called the International X-ray and Radium Protection Committee.

…mbers …sent	Officers
5	G. W. C. Kaye (United Kingdom), Chairman…
7	Do.
7	Do.
7	Do.
10	E. Rock-Carling (United Kingdom), Chairman… Taylor (United States), Secretary.
11	E. Rock-Carling (United Kingdom), Chairman… (United Kingdom), Secretary.
12	Do.

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… Congress of Radiology is scheduled to … …rmal meeting of the ICRP has not been scheduled … Congress. For the period 1956–59, the officers of … Sievert (Sweden), Chairman; G. Failla (United … Binks (United Kingdom), Secretary.

…t—continued.)

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… called the International X-ray and Radium Protection…

Because of the confusion regarding accredited representation, introduced primarily by the United States but also by Germany and to a lesser extent by France, the chairman of the ICRP, Dr. G. W. C. Kaye, recommended that a single central committee be established within those countries having more than one radiological organization for the purpose of consolidating national recommendations for presentation at the next meeting of the Commission. It was suggested that the members of the ICRP take this up individually with the various groups in their countries.

As the United States representative to the international protection group, it became the responsibility of L. S. Taylor, to convey its recommendations to the various groups involved in this country, to convince them of its soundness, to obtain their approval and suggestions, and to organize a national committee which could deal most effectively with the protection problems faced at that time.

In September 1928, this question was discussed informally with the president of the American Roentgen Ray Society, at its annual meeting in West Baden, Ind. Similar discussions were held with the president of the Radiological Society of North America in December of that year. As a result of these discussions, these organizations agreed to consolidate their protection activities into a single committee. They further recommended that the committee's activities be centralized at the National Bureau of Standards for the following reasons:

(1) It had by that time established a definite long-range program in the general field of radiation protection;

(2) It had the only laboratory in the country as its primary interest the development of radiation-protection data and information;

(3) It had no intersociety or political ties and therefore could be expected to retain an independent position and viewpoint; and

(4) It provided the official United States representative to the International Commission on Radiological Protection.

The two radiological societies each recommended a physicist and a radiologist for membership in the proposed national committee, and the American Medical Association appointed a member to represent its viewpoints. It was also felt that representation of the X-ray equipment manufacturers would be desirable and each of the manufacturers was asked to nominate candidates for this representation. Of the nominations received, the manufacturers then chose two to serve as their representatives.

Thus, early in 1929, the initial organization of the Advisory Committee on X-ray and Radium Protection was established with L. S. Taylor acting as chairman and with the following participating organizations and representatives:

American Roentgen Ray Society: H. K. Pancoast and J. L. Weatherwax
Radiological Society of North America: R. R. Newell and G. Failla
American Medical Association: Francis Carter Wood
X-ray equipment manufacturers: W. D. Coolidge and W. S. Werner
National Bureau of Standards and ICRP: Lauriston S. Taylor

2. HISTORY

The first meeting of the Committee was held in September 1929, during the annual meeting of the American Roentgen Ray Society. As its first objective, the Committee undertook the preparation of recommendations on X-ray protection. These were published on May 16, 1931, as National Bureau of Standards handbook 15.

The next effort was directed toward the preparation of recommendations on radium protection. For this purpose, Dr. L. F. Curtiss was named to the Committee as the NBS representative for radium protection recommendations, and Dr. C. F. Burnam as the representative of the American Radium Society. The first handbook on radium protection, NBS handbook 18, was prepared by Drs. Curtiss, Burnam, Failla, Newell, Weatherwax, and Wood, and was published March 17, 1934.

Soon after the publication of handbook 15 on X-ray protection, very rapid developments were made in the X-ray field; by 1934 or 1935 it was recognized that this handbook would have to be revised. This task was undertaken by the original Committee, except for the replacement of Dr. Pancoast by Dr. Eugene P. Pendergrass as representative of the American Roentgen Ray Society. The revised recommendations were issued in July 1936, as NBS handbook 20.

It might be worth noting that in this handbook, there appeared for the first time the recommendation of a specific permissible exposure level (then called tolerance dose) of radiation that could be allowed for occupational exposure. The figure recommended was 0.1 roentgen per week. This permissible exposure level remained in force for 12 years and was used by the Manhattan District in its operations. It was subsequently changed as a result of NCRP action in about 1948.

The revision of handbook 18 on radium protection was next undertaken, and the new handbook (H 23) was issued August 25, 1938.

These two handbooks, H 20 and H 23, were accepted in this country as the primary guides for protection against X-rays and the radiations from radium. As noted above, they were also the primary guides in this field to the Manhattan project.

Through the war years, there was no formal activity by the Advisory Committee. During that time, however, most of the members of the Advisory Committee were drawn into the Manhattan District program and it was largely through their efforts that uniform safety regulations prevailed during that period.

During its early activities, it was customary for the full committee to work together on the development of protection recommendations. When completed, the recommendations were submitted through their respective representatives to the participating organizations for noting and approval. Formal approval was usually given at one of the regular business meetings of the societies. With the NBS as sponsor of the committee, the recommendations were published by the Government Printing Office as National Bureau of Standards handbooks thus receiving the usual NBS editorial processing.

In September 1946, an informal meeting of the Advisory Committee was held to discuss the extensive revision needed in the X-ray protection recommendations, particularly in the upper voltage regions. At this meeting, it was pointed out that protection problems had become too complex to permit their study and solution by the Committee as then constituted. It was recommended that steps be taken to secure the participation in this work of additional groups such as the Manhattan District and United States Public Health Service, military department, etc. This recommendation was presented to Dr. Condon, then Director of NBS, who communicated with the Manhattan District and the Public Health Service on October 8, 1946, inviting their participation through appointment of 2 representatives each (1 psysicist and 1 radiologist). In response to this invitation, in October 1946, Dr. Stafford L. Warren and Dr. K. Z. Morgan were appointed as representatives of the Manhattan District, and the Public Health Service named Dr. Howard L. Andrews and Dr. E. G. Williams.

The first formal postwar meeting of the committee was held on December 4, 1946. In the agenda for this meeting, it was pointed out that new data had become available since the issuance of the recommendations on X-ray protection, and that many new protection problems had arisen with the rapid expansion in the radiation yield (protection against neutrons, multi-million-volt X-rays, radioactive isotopes, etc.). It was suggested that the scope of the work be defined; and that consideration be given to organizing small working groups to deal with each of the problems, their completed reports to be submitted to the committee for approval.

3. ORGANIZATION

Discussions along these lines were held at the December 4, 1946, meeting, and as a result, it was agreed that the committee should be substantially enlarged and reorganized. At the same time, it was felt that the name of the committee should be made more inclusive and it was therefore renamed National Committee on Radiation Protection. The National Bureau of Standards was reaffirmed as the central coordinating agency for the work of the committee; sponsorship by an impartial agency was felt to be particularly advantageous in view of the various types of participating organizations (radiological societies, industry, government, and the possible inclusion of industrial and labor groups).

The general organization and operational procedures outlined below were agreed upon at this meeting, and have been the basis for the continuing operation of the committee:

1. The committee would consist of an executive committee, main committee, and as many subcommittees as necessary to consider the problems that come within the committee's scope.

2. The executive committee would be composed of five members appointed by the chairman and subject to the approval of the main committee. The committee chairman would act as chairman of the executive committee.

3. The main committee would be composed of (1) technically qualified representatives appointed by organizations interested in the scientific and technical aspects of radiation protection, (2) representatives at large whose services are felt to be of special value, appointed by the executive committee and (3) chairmen of subcommittees.

4. The choice, of chairmen and members of subcommittees would not be restricted to members of the main committee but would be based on the particular qualifications needed for the work. (In organizing subcommittee memberships, the following practice has been and still is followed: The subcommittee chairman is selected by the committee chairman with the approval of the executive committee; the subcommittee chairman chooses his working group, makes informal contacts, and submits to the committee chairman his membership selections; the committee chairman issues formal membership invitations to serve on the subcommittees. Additions may be made to the subcommittee membership if particular specialized information is found to be needed, or individuals may be invited to serve as consultants to the group with due acknowledgment of their assistance included in the published recommendations.)

5. The final reports of the subcommittees would be submitted to the executive and main committees for approval. Because of the high degree of success of the NBS handbook series, it was recommended that this mode of publication and distribution to the public be continued.

Because of the reorganization and enlargement of the committee, the chairmanship was thrown open for reconsideration . L. S. Taylor was nominated and approved by vote to continue indefinitely in this capacity.

Discussions were held regarding the organizations that might appropriately be invited to participate and the suggestions made were used as a basis for the subsequent enlargement of the representation on the main committees.

It was agreed to establish the following subcommittees:

1. Permissible external dose
2. Permissible internal dose
3. X-rays up to 2 million volts
4. Heavy ionizing particles (neutrons, protons, and heavier)
5. Electrons, radium, and X-rays above 2 Mev.
6. Radioactive isotopes, fission products, including the handling and disposal
7. Monitoring methods and instruments

With the formulation of these basic philosophies, the committee began its active program. Its accomplishments and growth since its reorganization in 1946 can be seen by the appended list of handbooks published to date, and the appended membership list showing the present representation, subcommittee structure, and complete membership.

Recommendations of NCRP, 1931–55

NBS Handbook No.	Title	Date
[illegible]	X-ray protection: Superseded by H-20	May 16, 1931.
[illegible]	Radium protection for amounts up to 300 mg.: Superseded by H-23	Mar. 17, 1934.
[illegible]	X-ray protection: Superseded by H-41	July 24, 1936.
[illegible]	Radium protection: Superseded by H-54	Aug. 25, 1938.
[illegible]	X-ray protection up to 2,000,000 volts: Superseded by H-60	Mar. 30, 1949.
[illegible]	Safe handling of radioactive isotopes	September 1949.
[illegible]	Control and removal of radioactive contamination in laboratories	Dec. 15, 1951.
[illegible]	Recommendations for waste disposal of phosphorus 32 and iodine 131 for medical users.	Nov. 2, 1951.
[illegible]	Radiological monitoring methods and instruments	Apr. 7, 1952.
[illegible]	Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water.	Mar. 20, 1953.
[illegible]	Recommendations for the disposal of carbon 14 wastes	Oct. 26, 1953.
[illegible]	Protection against radiations from radium, cobalt 60, and cesium 137	Sept. 1, 1954.
[illegible]	Protection against betatron-synchrotron radiations up to 100,000,000 electron volts.	Feb. 26, 1954.
[illegible]	Safe handling of cadavers containing radioactive isotopes	Oct. 26, 1953.
[illegible]	Radioactive-waste disposal in the ocean	Aug. 25, 1954.
[illegible]	Permissible dose from external sources of ionizing radiation	Sept. 24, 1954.
[illegible]	X-ray protection	Dec. 1, 1955.
[illegible]	Regulation of radiation exposure by legislative means	Dec. 9, 1955.

Exhibit 15. List of Reports of NCRP

References

NBS Circular No. 374, X-ray and radium protection. (Recommendations of the International Congress of Radiology, January 1929)

Handbooks	
18	Radium Protection for Amounts up to 300 Milligrams, 1934
20	X-Ray Protection, 1936
23	Radium Protection, 1938
41	Medical X-Ray Protection up to Two Million Volts, 1949
42	Safe Handling of Radioactive Isotopes, 1949
47	Recommendations of the International Commission on Radiological Protection and of the International Commission on Radiological Units, 1951
48	Control and Removal of Radioactive Contamination in Laboratories, 1951
49	Recommendations for Waste Disposal of Phosphorus 32 and Iodine 131 for Medical Users, 1951
50	X-Ray Protection Design, 1952
51	Radiological Monitoring Methods and Instruments, 1952
52	Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water, 1953
53	Recommendations for the Disposal of Carbon 14 Wastes, 1953
54	Protection Against Radiations From Radium, Cobalt 60, and Cesium 137, 1954
55	Protection Against Betatron-Synchroton Radiations up to 100 Million Electron Volts, 1954
56	Safe Handling of Cadavers Containing Radioactive Isotopes, 1953
57	Photographic Dosimetry of X- and Gamma-Rays, 1954
58	Radioactive-Waste Disposal in the Ocean, 1954
59	Permissible Dose From External Sources of Ionizing Radiation, 1954
60	X-Ray Protection, 1955
61	Regulation of Radiation Exposure by Legislative Means, 1955
62	Report of the International Commission on Radiological Units and Measurements (ICRUO 1956)

Current Handbooks in Process

Handbooks	
59	Modification A [1]
52	Modification A—Also increasing coverage from 100 to 300 radioisotopes and revising some of the old MPC's
60	Modification A [1]
63	In Press. "Protection Against Neutrons"
--	"Safe Handling of Radioactive Isotopes"—complete revision of H-42
54	Modification A [1]
61	Modification A [1]
--	"Incineration of Radioactive Waste"—completion in about 6 months
--	"Protection Against High Intensity, High Energy Electrons"—mainly for food sterilization programs
56	Modification A [1]
50	Modification A [1]
—	"Radiation Exposure Under Emergency Conditions"—treatment of problem of large and small radiation doses mainly under civil defense or civil disaster conditions
	RBE Values for All Radiations

[1] Modification mainly to reflect the new permissible dose levels of January 8, 1957.

(Mr. Taylor's statement—continued.)

Since the war the recommendations of the ICRP have been guided, in a large measure, from those developed by the NCRP and the international recommendations and standards reflect pretty generally the United States standards. This is not surprising when one considers that the shaping of the program and the chairmanship of some of the committees on the ICRP are in the same hands as of corresponding subcommittees of the NCRP.

EXHIBIT 16. RELATIONSHIP BETWEEN THE WORK OF THE NCRP AND THE INTERNATIONAL COMMISSIONS

OCTOBER 1956.

RELATIONSHIP BETWEEN THE WORK OF THE NCRP AND THE INTERNATIONAL COMMISSIONS

As noted in the foregoing, the NCRP has been a very active continuing organization since its inception in 1929. Also because of the very much greater activity in the radiation field in the United States as compared with most other countries, the NCRP has been able to develop much more detailed information in matters of radiation protection. For this reason, it is not unnatural that there should have been a number of areas in which the general recommendations and philosophies of the NCRP have influenced the international recommendations. A major example was the adoption by the ICRP in 1950 of the lower maximum permissible exposure levels recommended by the NCRP 2 or 3 years earlier and already in use in this country. The adoption of these levels was also facilitated by the tripartite conferences between England, Canada, and the United States, the results of which were based on the information supplied by the NCRP.

When the ICRP subcommittee structure was first established in 1950, it was patterned fairly closely after that already in use for several years by the NCRP. In fact the chairman selected for subcommittees I and II of the ICRP were the chairman of the corresponding subcommittees of the NCRP. In addition, many of the individuals selected for membership on the other subcommittees of the ICRP were members of the corresponding NCRP subcommittees.

The maximum permissible concentrations of radioactive isotopes in the body, and in air and water, which were included in the 1950 ICRP report, were those developed initially by the NCRP for its Handbook 52, then in the course of preparation.

In the report of the ICRP developed in 1953, the reports by three of the subcommittees (on permissible dose from external and from internal sources of radiation and on X-ray protection) were taken very largely from the corresponding reports developed by the NCRP. In fact, these NCRP reports were used as the basis for consideration of these subjects by the ICRP.

Similar close relationships have existed between the NCRP and the ICRU. It could not be said with fairness that the most recent recommendations of the ICRU reflect dominantly the opinion of any one group, as all of the representatives participated actively in its preparation . On the other hand, the new committee structure of the ICRU is patterned after that which had been adopted by the NCRP a short time previously. With this extension of activities, the ICRU organizational structure now includes the following:

Committee I, Standards and Measurements of Radioactivity for Radiological Use
Committee II, Standards and Measurements of Radiological Exposure Dose
Committee III, Measurement of Absorbed Dose and Clinical Dosimetry
Committee IV, Standard Methods of Measurement of Characteristic Data of Radiological Equipment and Material

Throughout the membership composition of these four committees, there is substantial overlap in both officers and members with the corresponding subcommittees of the NCRP.

(Mr. Taylor's statement—continued.)

The National Committee on Radiation Protection (NCRP) is currently sponsored by the National Bureau of Standards and is made up of representatives of various scientific and technical organizations and governmental departments. In this way, there is close coordination between the committee's activities and those of other interested groups. This applies particularly to the relationships with the AEC with whom there is the closest collaboration. In fact, the Atomic Energy Commission supplies a small allotment of funds to the NCRP for its work. At the same time, the recommendations of the NCRP are made without undue influence on the part of the AEC.

EXHIBIT 17. LIST OF NCRP PARTICIPATING ORGANIZATIONS, SUBCOMMITTEE MEMBERS, MEMBERSHIP OF EXECUTIVE COMMITTEE, JULY 1956

Lauriston S. Taylor, chairman
Sarah W. Raskin, secretary

EXECUTIVE COMMITTEE

C. L. Dunham
G. Failla
R. S. Stone
L. S. Taylor
E. G. Williams

MAIN COMMITTEE (AND ORGANIZATION REPRESENTED)

H. L. Andrews, USPHS and subcommitte chairman
E. C. Barnes, American Industrial Hygiene Association
A. C. Blackman, International Association of Government Labor Officials
C. B. Braestrup, subcommittee chairman
J. C. Bugher, representative at large
R. H. Chamberlain, American College of Radiology
W. D. Claus, USAEC
C. L. Dunham, USAEC
T. P. Eberhard, American Radium Society
T. C. Evans, American Roentgen Ray Society
G. Failla, Radiological Society of North America and subcommittee chairman
P. C. Hodges, American Medical Association
H. W. Koch, subcommittee chairman
S. E. Lifton, Colonel, United States Air Force
W. Langham, subcommittee chariman
E. A. Lodmell, Colonel, United States Army
W. B. Mann, subcommittee chairman
G. W. Morgan, subcommittee chairman
K. Z. Morgan, representative at large and subcommittee chairman
R. J. Nelsen, American Dental Association
R. R. Newell, American Roentgen Ray Society
H. M. Parker, subcommittee chairman
E. H. Quimby, American Radium Society and subcommittee chairman
S. W. Raskin, National Bureau of Standards
J. A. Reynolds, National Electrical Manufacturing Association
H. H. Rossi, subcommittee chairman
M. D. Schulz, American College of Radiology
L. S. Skaggs, subcommittee chairman
J. H. Sterner, American Industrial Hygiene Association
R. S. Stone, Radiological Society of North America
I. R. Tabershaw, International Association of Government Labor Officials
L. S. Taylor, National Bureau of Standards
E. D. Trout, National Electrical Manufacturing Association
Shields Warren, representative at large
J. L. Weatherwax, representative at large
E. G. Williams, USPHS
S. F. Williams, Captain United States Navy
H. O. Wyckoff, subcommittee chairman

SUBCOMMITTEE 1. PERMISSIBLE DOSE FROM EXTERNAL SOURCES

G. Failla
A. H. Dowdy
H. Friedell
H. J. Muller
H. M. Parker
K. Stern
R. S. Stone

SUBCOMMITTEE 2. PERMISSIBLE INTERNAL DOSE

K. Z. Morgan, chairman
A. M. Brues
G. Failla
J. G. Hamilton
L. D. Marinelli
H. M. Parker
J. E. Rose
Shields Warren

these data appear sound, they may still be considered incomplete and there are minor discrepancies which have appeared and which may require some study/tion. There is also reason to discuss the place of the production of mutations compared with the general mutations that are being retained in the genetic pool.

The radiation dose necessary to double the mutation rate appears to be about 50 roentgens. It should be clearly understood that this is an estimate, and competent geneticists have submitted proposals from 5 to 150 roentgens.

It is known that there are many diseases of heredity (that is, genetic origin) which are almost certainly the result of mutants and may therefore be examined in the same light as mutants due to radiation. Since these may be retained in the pool because of the amelioration of the rigors of selection, it would be possible to assess all of these mutants in terms of roentgens. Therefore, a better estimate of the total hazard as a result of low doses of radiation would be possible.

It appears that most mutations appear to be of the recessive variety which would therefore, in effect, not permit their immediate recognition or elimination until after many, many generations. This means that the mutant will become widely disseminated in the genetic pool. It also means that the radiation received by a small segment of society may be of little consequence since the radiation to the total population would be roughly the ratio of the total population to this small segment. The genetic effects are best surveyed from the point of view of its effect on the whole population and, generally speaking, the genetic effects become significant when delivered to either the whole population or large segments of it.

I am inclined to make these observations from the point of view of long-term effects of radiation—that is, the production of tumors, leukemia, and the decrease in longevity.

All data presented at the present time are either presumptive or speculative for very low doses. They rest in hypotheses derived from the theoretical aspects of dose effects at high levels. I believe there is sufficient uncertainty so that it would be unwise, and in fact nonscientific, to make conclusive decisions on the basis of these extrapolations.

With respect to the genetic effects, which have been extensively studied by biologists, there are sufficient uncertainties even in these data so that it is not possible to accept them as entirely unassailable. These include the fact that data at low levels do not exist, that data are confined at present to Drosophila and to a few small mammals such as mice, that the mutation rate due to ultraviolet radiation appears to be nonlinear, and there is reason to believe that some of the energy transfer with ionizing radiation is in part of the same character as that with ultraviolet radiation. Man has existed since time immemorial in a sea of radiation where fairly large differences because of altitude and special geographic places also are present. It is difficult to reconcile some of the conjectures to be made at very low levels with the natural radiation doses to which man has already been subjected.

To my mind, the problems of biologic effects at low doses are in essence these:

1. The data on the biological effects at low levels of radiation are by no means conclusive. At best they must be considered highly presumptive. This suggests that extensive, carefully considered research is necessary.

2. Even if one assumes that the low-level effects of radiation are established, the problem of establishing the hazard and the risk rate at these levels has not yet been fully and properly evaluated. With specific regard to the fallout problem, it is my opinion that at the low levels which now appear to exist, no immediate decision on any vital problems is now necessary.

With respect to the general overall consideration regarding all-out nuclear warfare, a different order of magnitude is introduced and I must join with others in pointing out that this is fraught with the direst consequences, and that every effort must be expended to the elimination of nuclear warfare.

With specific respect to the fallout problem, it is my opinion that with the low levels which now exist, no precipitate alteration in our course is required. There are a number of organizations on radiation protection that are continually looking at this problem with representatives of all disciplines, and they are gradually modifying the acceptable levels wherever it is found desirable.

Reference App 911-912

Representative HOLIFIELD. Before we hear our next witness, I would like to insert in the record a report from the Armed Forces Institute of Pathology.

(The report referred to follows:)

ARMED FORCES INSTITUTE OF PATHOLOGY,
WALTER REED ARMY MEDICAL CENTER,
Washington, D. C., May 16, 1957.

Subject: Statements for congressional hearings.
To: Chief of Research and Development, Department of the Army, Washington, D. C.
(Attn. Chief, Atomic Division.)

The following report is submitted in accordance with a verbal request to the Director of the Armed Forces Institute of Pathology from Lieutenant Colonel Johnson of the Research and Development Office of the Department of the Army, May 14, 1957. The time limit of 24 hours for the preparation of such an extensive report, and the absence on TDY of the Chief and Assistant Chief of the Section on Radiobiology, Armed Forces Institute of Pathology at the Nevada test site on Operation Plumbob 4.1 necessarily resulted in some limitation on presentation of material requested which under more favorable circumstances could possibly be more fully covered. The discussions and answers as presented represent a combined effort of the professional staff of the Armed Forces Institute of Pathology with some assistance obtained from Naval Medical Research Institute and Walter Reed Army Institute of Research.

W. M. SILLIPHANT,
Captain, MC, USN, The Director.

CONCERNING TOPIC IX

A detailed discussion of the occurrence of strontium 90 and cesium 137 in the atmosphere and its uptake and behavior in man is contained in the remarks prepared by Dr. Willard F. Libby, Commissioner, United States Atomic Energy Commission, for delivery before the spring meeting of the American Physical Society, Washington, D. C., April 26, 1957. A copy is attached (see p. 1519). These findings have also been discussed and confirmed by Drs. J. L. Kulp, W. R. Eckelmann, A. R. Schulert (Strontium 90 in Man. Science, 125, p. 219, February 8, 1957). However, Dr. Lapp (Science, vol. 125, p. 933, May 10, 1957) criticizes some of these conclusions, and points out some pertinent factors for consideration. His critique is attached (see pp. 694, 704).

CONCERNING TOPIC X

SOMATIC EFFECTS—PATHOLOGY

A. Distinction must be made between the somatic and genetic effects of radiation

The genetic cells carry on from generation to generation the damage which has been received. The somatic cells receive the injury but this is not transmitted from one generation to another. The effects of high level radiation may be manifested not only immediately but also after a delayed period. There are also effects from a low level of radiation and some organs are more readily injured than others.

B. Early effects of exposure of animals and man to external radiation

1. *Gama and X-radiation.*—Syndrome of radiation sickness. Individuals receiving doses of total body radiation can probably be best divided from a standpoint of prognosis according to the clinical signs and symptoms they present. This is particularly true because of individual variation in the response of different people to the same dose of irradiation. Roughly, casualties may be grouped into those in which survival is improbable, possible, and probable.. There is, however, no very sharp line of demarcation among the groups. The signs and symptoms have been described for the Japanese casualties at Hiroshima and Nagasaki in a report by Liebow, Warren, and DeCoursey in the American Journal of Pathology and in a report entitled "Some Effects of Ionizing Radiation on Human Beings" involving particularly the Marshallese casualties. In doses of more than 3,000 roentgens one may encounter a hyperacute reaction within an hour whereas in the range of about 3,000 to 2,000 roentgens nauseau, vomiting, and some diarrhea and fatigue may be the initial reaction in 2 to 4 hours after exposure. In individuals receiving doses between the range of 2,000 down to 800 roentgens there may be a period of relative well-being following the initial reaction for a few days and then a gradual return of

anorexia, malaise, severe diarrhea, thirst, fever, delirium, and leucopenia. In individuals between 800 and 300 roentgens this reaction may come in about 2 to 3 weeks with acute bone marrow failure, ulceration of the gastrointestinal tract, epilation, and bacterial infection. A subacute reaction consisting of subacute marrow failure, subacute infection in the lungs, brain, and bowel and general malnutrition may manifest itself in about 6 weeks after exposure in patients receiving 350 to 250 roentgens. In those receiving less than 250 roentgens and in some survivors from doses in the lethal range, there may be a chronic reaction of varying degrees extending for a period of months or longer of malnutrition, chronic anemia, premature aging, leukemia, and possibly neoplasia. The above acute syndrome varies with the geometry of the source of radiation *in relation to the exposed person.*

(*a*) Marshallese: See reference.

(*b*) The Los Alamos incidents referred to under X. B, 1, b are covered in a single entire issue of the Annals of Internal Medicine February 2, 1952.

2. *Beta radiation—Beta burns.*—As long as only very penetrating radiations are involved in exposure of the entire body, skin injury would rarely be a problem, because a dose sufficient to permanently affect it would kill the patient before dermatologic lesions were of any concern. Epilation is an exception to this statement since it was present, though only temporarily, in some of the Japanese atom-bomb victims. During fallout from bomb clouds, however, radioactive particles may settle on the exposed skin of anyone outdoors, and the *hazards of beta particle radiation burns are added to the effect produced by* penetrating gamma rays. Beta particle burns resulting from fallout first came into public prominence with the announcement that some of the inhabitants of the Marshall Islands were exposed to such a hazard during the 1954 weapons-testing program. However, the problem of fallout was not a new thing to those charged with the responsibility of conducting tests of nuclear weapons. At the time of the first nuclear detonation at Alamagordo, N. Mex., a number of cattle about 10 miles from the blast received fallout on their backs. The fine particles were retained by the hair, and in a few weeks epilation and blisterlike lesions occurred. The lesions healed much like ordinary thermal burns, and the hair grew again, but the original red color was replaced by grey or white. *Late effects of this exposure have recently been reported in studies conducted at the* AFIP.

(*a*) Marshallese: In the Marshallese group individuals were exposed to gamma and beta radiation. The injuries due to beta burns were local and confined to the areas of contact. The reaction manifested itself by initial tingling and itching at the time of exposure, followed by erythema and edema in a few hours, lasting for 2 to 3 days. There was then a latent asymptomatic 3- to 5-day period with a return of secondary erythema with vesicle formation. Drying and desquamation takes place in about 3 weeks and the individual then may enter a chronic phase with some atrophy of the involved parts taking place. Where both types of radiation occur concomitantly, the gamma radiation *generally overrides the beta in clinical significance.*

The effects of ionizing radiation amongst the Marshallese has been extensively covered in the report Some Effects of Ionizing Radiation on Human Beings from the Naval Medical Research Institute, Bethesda, Md.; United States Naval Radiological Defense Laboratory, California; and Medical Department, Brookhaven National Laboratory, Upton, N. Y.; United States Atomic Energy Commission, July 1955. Values for gamma and beta radiation could only be approximated but there was a high enough dose on the skin to produce lesions. The estimated "point source" doses were:

Rongelap, group I, 260 r.
Uterik, group IV, 20 r.

Some of the patients showed *acute symptoms* of diarrhea and vomiting and itching and burning of the skin in group I (Rongelap) but none in group IV (Uterik) showed these symptoms. Biopsies were taken of the skin at various stages. These showed changes typical of radiation reaction. Ultimately there was complete restoration of the skin.

(*b*) Other examples: Skin lesions, acute, chronic and neoplastic were one of the earliest hazards to be recognized in human beings exposed to low energy radiation. Human casualties from ionizing radiation have been of increasing *concern since the turn of the century. These include in addition to skin lesions,* a higher incidence of leukemia among radiologists than among the general population. The occurrence of cataracts among early workers with cyclotrons, the

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

Our first witness this afternoon is Dr. Eugene Cronkite of the Brookhaven National Laboratory. He is a senior physician there.

At this time we will be glad to have your testimony, Doctor Cronkite.

I understand that your testimony will take up the subject of the effect on the Marshallese Islanders this afternoon.

Reference & Introd. for pp 941-954

STATEMENT OF DR. EUGENE P. CRONKITE, BROOKHAVEN NATIONAL LABORATORY[1]

Dr. CRONKITE. That is right, Mr. Holifield. With your permission I would like to state that due to duties I had in Nevada I was unable to properly proofread the prepared testimony and would like permission to do so later in the week.

In addition, since the subject material is rather extensive, I would like to submit for the record the official report on the Marshallese incident and also the 6-month, the 1-year, and the 2-year reports.

Representative HOLIFIELD. Without objection, they will be received and filed with the committee.

Dr. CRONKITE. In the prepared statement, I will just mention that the first nine pages go over the general problems of whole body radiation of man, and I am essentially in agreement with all that Dr. Friedell has said this morning.

I would like to make one comment in respect to the treatment of radiation injury that came up this morning. That is, that much has been learned from the experimental therapy of radiation injury in animals. It has been conclusively shown that protection can be afforded by the transplantation of bone marrow from one strain of animal to another. The protection afforded by transplantation of genetically specific material; that is, from one member of the same strain to an irradiated member of the same strain, is very good and long last-

[1] Born December 11, 1914, *Los Angeles, Calif.* Undergraduate studies, University of California at Los Angeles and Stanford University. A. B. Stanford University, California, 1936. M. D. Stanford University, School of Medicine, San Francisco, Calif., 1941. 1940–41, interne in medicine, Stanford University Hospitals, San Francisco, Calif. 1941–42, assistant resident in medicine, Stanford University Hospitals, San Francisco, Calif. May 1942, commissioned lieutenant (junior grade), Medical Corps, United States Navy. 1943, under instruction in general surgery, U. S. Naval Hospital, Naval Operating Base, Norfolk, Va., under J. M. Deaver. 1943–44, *medical officer,* Third Marine Aircraft Wing, FMF, U. S. Marine Corps Air Station, Cherry Point, N. C., and U. S. Marine Corps Air Facility, Walnut Ridge, Ark. 1945, medical officer, U. S. S. *Sylvania* AKA 44. 1946–54, head, *Hematology Division,* Naval Medical Research Institute, Bethesda, Md. 1946, participated as hematologist, Operation Crossroads, atomic bomb field tests, Bikini, Marshall Islands. 1950–51, project officer, Operation Crossroads, biological effectiveness of atomic bomb gamma radiation and hematological studies. 1952, assistant project officer, biological effectiveness of neutrons, Operation Tumbler-Snapper, Nevada Proving Ground. 1953, director biomedical program, Operation Upshort/knothole, civil effects test group. 1954, Operation Castle, project officer for the study of accidental human radiation casualties. *Recipient Sir Henry Wellcome Prize in Military Medicine,* 1949. Secretary of the Army Commendation for work, Operation Castel, 1954. Member of Phi Beta Kappa 1937; Olpha Omega Olpha 1940; Sigma Xi 1943; Fellow of the American Medical Association: American Association for the Advancement of Science Society for Experimental Biology and Medicine; American Federation of Clinical *Research; International* Society of Hematology; American Physiological Society; New York Academy of Science; American Society for Clinical Investigation. Resigned from the United States Navy September 30, 1954, *as commander,* Medical Corps, United States Navy. Presently senior physician, head of Division of Experimental Pathology, Medical Department, Brookhaven National Laboratory. Member National Research Council civil defense committee. Member of National Academy of Sciences panel to evaluate the acute and chronic effects of atomic radiation on man. Chairman of National Academy of Sciences *subpanel of* acute and chronic hematologic effects of atomic radiation on man. Member of Advisory Committee Atomic Bomb Casualty Commission. (Submitted by witness.)

ing. If the material for transplantation has its source in another strain of mouse, the protection is less marked or not as long lasting. If the protective material comes from another species of animal, the protection is very short lived and not nearly as effective. In principle, the transplantation of bone marrow would significantly increase the survival rate of exposed human beings to doses of radiation that would be uniformly fatal. The amounts of bone marrow needed are large, and the mongrel nature of man makes it unlikely that very much could be expected in the way of long-term protective effect. In my opinion it would be the worst type of wishful thinking to expect that one could have an effective bone-marrow bank in the case of an atomic catastrophe. Much work is yet to be done under carefully controlled clinical conditions before one could be optimistic about the use of this procedure in man under highly controlled conditions in an individual patient, let alone under conditions of a nuclear catastrophe.

With this general statement I would also like to state that certainly in human beings exposed in the midlethal dose of radiation, the clinical picture of which is very similar to that produced by depression of bone marrow due to various drugs and so on, one would expect that antibiotics and judicious use of blood transfusions would be most helpful in increasing the survival rate in the midlethal range but not in the range in which spontaneous survival is not likely at the present time.

With these general comments I would like to go to the prepared statement.

I have been asked to summarize the early effects of exposure of animals and man to external radiation with particular reference to the effects of fallout radiation on the Marshallese, the Los Alamos accident, and radium. In addition, I have been asked to comment on the beta burns in the Marshallese, and other examples of beta burns. Since my personal experience is limited to the Marshallese and animal experimentation, I shall limit myself to these and supply reference material for the others.

It is quite impossible to cover all of this material in a reasonable period of time, so I shall concentrate upon the effects of exposure to external radiation on animals and man with a clinical description of the syndrome of radiation sickness as a function of dose of radiation and highlight the discussion with illustrative material collected in the study of the Marshallese (reference 1).

My prepared statement includes numerous references and further material that time will not permit discussion of at length here.

Radiation syndromes vary as a function of the type of exposure, the dose, and the time after exposure to radiation. In general radiation injuries can be divided into three general classes:

(*a*) The syndromes of whole body radiation injury produced by penetrating ionizing radiation which are dose and time dependent.

(*b*) Superficial radiation burns produced by soft radiations—beta and low energy x or gamma radiations.

(*c*) Radiation injury produced by the deposition of radionuclides within the body.

In the latter case the clinical picture varies with the site and amount of deposition.

helpful to a limited extent for anemia. The probability of availability of enough blood for burns and other injuries is low. Hence, when blood may be needed for radiation injury, supply may be exhausted. Preparation and stockpiling for such an emergency is obviously required.

GROUP III SURVIVAL PROBABLE

This group consists of individuals who may or may not have had fleeting nausea and vomiting on the day of exposure. In this group there is no further evidence of effects of the exposure except the hematologic—blood—changes that can be detected by serial studies of the blood with particular reference to lymphocytes and platelets. The lymphocytes reach low levels early, within 48 hours, and may show little evidence of recovery for many months after exposure. The granulocytes may show some depression during the second and third week. However, considerable variation is encountered. The late fall in the granulocytes, during the sixth or seventh week, may occur and should be watched for. Platelet counts reach lowest levels on approximately the 30th day at the time when maximum bleeding was observed in Japanese who were exposed at Hiroshima and Nagasaki. This time trend in the platelet count and the development of hemorrhage is in marked contrast to that seen in laboratory animals where platelets reach their lowest levels between the 10th and 15th days and hemorrhage occurs shortly thereafter.

In this group individuals with neutrophil counts below 1,000 per cubic millimeter may be completely asymptomatic. Likewise, patients with platelet counts of 75,000 per cubic millimeters or less may show no external signs of bleeding.

It is well known that all defenses against infection are lowered, even by sublethal doses of radiation, and thus, patients with severe hematologic depression should be kept under close observation and administered appropriate therapy as indicated. There is reasonably good animal experimentation to indicate that sublethally exposed colonies of animals are more susceptible to endemic and epidemic infection.

The numbers of individuals in group III—survival probable—will be greater than in group II—survival possible—and the number in group II will be greater than in group I—survival improbable. Group I casualties will be helplessly injured. Group II casualties will be able to help in their own care to a limited extent. Group III casualties will be useful and a moderate amount of work will not be harmful. No therapy other than observation is needed for this group.

The rest of my comments will be focused on the fallout accident that occurred on March 1, 1954.

Following detonation, unexpected changes in the wind structure deposited radioactive materials on inhabited atolls and on ships of Joint Task Force 7, which was conducting the tests.

Radiation surveys of the areas revealed injurious radiation levels; therefore evacuation was ordered, and was carried out as quickly as possible with the facilities available. Although the estimated accumulated doses to human beings were believed to be below dangerous levels that would produce lasting injury or mortality, the commander of the task force requested assistance of the Department of Defense and the United States Atomic Energy Commission. A medical team was requested which would be organized to provide the best possible care of the exposed persons and to make a medical study of the exposures. The responsibility for organization of the medical team was shared between the Armed Forces special weapons project of the Department of Defense, and the Division of Biology and Medicine of the Atomic Energy Commission.

Since speed was essential, and since the United States Navy Medical Department had experienced personnel available at the Naval Medical Research Institute and the United States Naval Radiological Defense Laboratory, the Surgeon General of the Department of the Navy was requested to provide assistance.

He promptly complied, and directed the organization of a team from the two above-mentioned laboratories. I had the privilege to be the director of this team.

Within a period of 3 days, equipment was assembled and packed, and the team was airlifted to the Marshall Islands, arriving on the eighth day after the explosion.

The interim care and study of the exposed individuals had been ably taken care of by the limited medical facilities of the United States Naval Station, Kwajalein. I am pleased to call attention to the fact of the very high degree of cooperation between all Government agencies concerned and to the numerous individuals who selflessly gave of their time and efforts. The number is large, and due credit and acknowledgments are given in the official report of the incidence published by the United States Government Printing Office, and listed in reference 1.

NATURE OF THE EVENT AND DESCRIPTION OF THE EXPOSED GROUPS

The radioactive material fell on the inhabited atolls of Rongelap, the heaviest dose; on Ailinginae; on Rongerik where American servicemen were stationed, and Utirik where the smallest dose was received, but by the largest number of people. The Marshallese were living under relatively primitive conditions in lightly constructed palm houses.

The American military personnel had the second highest exposure. They were more aware of the significance of the fallout than where the Marshallese, and promptly put on additional clothing to protect their skin. As far as duties would permit, they remained inside of aluminum buildings. In contrast to this the Marshallese in general remained outside, and accordingly were more heavily contaminated by the material falling upon the atoll and upon them.

All of the exposed human beings were evacuated by air and surface transportation to the United States naval station, Kwajalein, as promptly as facilities would permit. Since a survey of the individuals showed that there was significant contamination of the skin, clothes, and hair, the clothes were removed and laundered and repeated washings of the skin and hair were carried out with fresh water and soap. The hair of the Marshallese was decontaminated with difficulty because of the heavy coconut-oil hair dressing they used.

On Rongelap there were 64 individuals that received an estimated dose of 175 r. On Airlinginae there were 18 individuals receiving approximately 69 r. On Rongerik there were 28 American servicemen receiving approximately 78 r. on Utirik there were 157 individuals receiving approximately 14 r.

Senator ANDERSON. Where do you get those figures, Doctor?

Dr. CRONKITE. I will come to that in the next section. I will discuss how the doses were arrived at.

Senator ANDERSON. We heard it suggested this morning that lots of figures are not too reliable. I am wondering if you had a way of measuring this so you could be fairly sure of these figures.

Dr. CRONKITE. I will come to this in the next section and discuss the reliability of the dose estimates and the various variables that go into it.

Senator ANDERSON. Thank you.

WHOLE BODY GAMMA DOSES

Dr. CRONKITE. The determination of the whole body gamma doses are dependent upon the surveys that were made with calibrated instruments approximately 3 feet above the ground several days after the inhabitants were evacuated. In addition certain assumptions had to be made about the arrival time of the cloud and the rate of fallout of the material. Only on Rongerik where there was a recording dosimeter is arrival time known precisely. The dose rate of the continuing fallout of material was in part neutralized by the progressive radioactive decay. In addition the transit dose from the cloud passing over the atolls could not be estimated. All of these variables were taken into account and the doses calculated. These doses were consistent with the doses that were actually measured on Rongerik by film that was stored in refrigerators and by film exposed outside on this atoll.

In view of this internal consistency it is believed that the dose of calculated radiation on the atolls is reasonably accurate. Details of the calculation of the dose are in the official report which discusses in detail the probable range in values (reference 1, ch. 1).

CHARACTERISTICS OF THE GAMMA RADIATION

The fallout material when deposited on the ground formed a large planar source of radiation. The energy distribution of the radiation reaching an exposed individual is influenced by its passage through the intervening air. A knowledge of the inherent gamma spectrum as it eminates from the material itself is essential in order to determine the spectrum that impinges upon exposed individuals.

When one takes into account the spectometric data on the mixed fission products and the degredation by Compton scattering along the path in air, a dose energy histogram can be constructed, showing that there are roughly 3 regions with maxima at 100, 700, and 1500 Kev. The total exposure is thus the resultant effect of partial doses from each energy region, making the exposure energy condition significantly different from those of radiation therapy, experimental biology, or from the prompt gamma radiation of the bomb.

Details of the characteristics of the exposure are discussed in reference (reference 1, ch. 1).

Actually the overall effect of the geometry and spectrum is to produce a very uniform deposition of energy throughout the body so that per roentgen in air fallout radiation is relatively more effective than the prompt radiation from the bomb or the radiation from an X-ray tube.

THE CHARACTERISTICS OF THE FALLOUT MATERIAL

The fallout material consisted predominantly of flakes of calcium oxide resulting from the incineration of the coral. Upon the flakes of calcium oxide fission products were deposited. At Rongelap Atoll the material was visible and described as snowlike. It stuck to the skin, adhered to the air and clothes, the vegetation, and the habitations.

Senator ANDERSON. That is what they talked about with respect to the Japanese who were in the fishing boat.

Dr. CRONKITE. Yes, sir.

Senator ANDERSON. They had this white fallout that they thought was some sort of manifestation from heaven and would not wash off for a while, and suffered as a consequence. You are describing the same sort of thing that happened down there.

Dr. CRONKITE. They were in approximately the same or a comparable position as the Rongelap natives and experienced very closely the same thing, except in their case working with their fishlines, and so on, grinding the material into their hands, they got worse skin burns than the Marshallese.

Senator ANDERSON. Thank you.

GEOMETRY OF THE EXPOSURE

Dr. CRONKITE. Time does not permit a discussion of the effect of this, but it has been alluded to earlier and details of the influence of geometry of the exposure to biologic effect are in references 1 and 17.

SUPERFICIAL DOSES OF RADIATION FROM BETA AND SOFT GAMMA RADIATION

There is no doubt that the dose of radiation to the first few millimeters of the skin is substantially higher than that at the midline of the body from the more penetrating gamma component. Problems concerned with the estimation of the dose of radiation to the skin are discussed in detail in reference 1, chapter 1.

To arrive at some physical estimate of the skin dose, an attempt must be made to add up the contributions of the penetrating gamma, the less penetrating gamma, the beta bath to which the individuals were exposed from the relatively uniform deposition of fission products in the environment and the point contact source of material deposited on the skin. By all means the largest component of skin irradiation resulted from the spotty local deposits of fallout material on exposed surfaces of the body.

To put it in reverse, the individuals who remained inside had no skin burn. It was only on those on whom the material was directly deposited on the skin that received burns.

It is completely impossible to estimate the dose from material that was deposited on the skin. The relative hazard of the beta path is discussed in detail in the previously mentioned reference 1.

CLINICAL OBSERVATIONS AND TREATMENT: SYMPTOMS AND SIGNS RELATED TO RADIATION INJURY

Itching and burning of the skin occurred in 28 percent of the people on Rongelap, 20 percent of the group on Ailinginae, and 5 percent of the Americans. There were no symptoms referable to the skin in the individuals on Utirik. In addition to the itching of the skin there was burning of the eyes and lacrimation in people on Rongelap and Ailinginae. It is probable that these initial skin symptoms were due to irradiation since all individuals who experienced the initial symptoms later developed unquestioned radiation-induced skin lesions that will be described in detail later. It is is possible however, that the intensely alkaline nature of the calcium oxide when dissolved in perspiration might have contributed to the initial symptoms.

About two-thirds of the Rongelap group were nauseated during the first 2 days, and one-tenth vomited and had diarrhea. One person in the Ailinginae group was nauseated. No one in the Rongerik or Utirik group, or Americans, had gastrointestinal symptoms.

CLINICAL OBSERVATIONS AND LEUKOCYTE COUNTS

Between the 33d and 43d post exposure day, 10 percent of the individuals from Roneglap had an absolute granulocyte level of 1,000 per cubic millimeter or less. The lowest count during this period was 700 per cubic millimeter.

Representative HOLIFIELD. How does that compare with the normal?

Dr. CRONKITE. The normal count would be approximately 5,000 to 6,000 in American population. They were very seriously depressed at this time.

Representative HOLIFIELD. This was with an average of around what?

Dr. CRONKITE. 175 roentgens. I am sorry I did not mention it earlier. I am limiting my comments to the highest dose group. The time sequence of events in the other groups was similar but just to a less extent more or less proportionate to the decrease in dose received.

During this interval the advisability of prophylactic administration of antibiotics was seriously considered. However, prophylactic administration of antibiotics was not instituted for the following reasons:

(1) All individuals were under continuous medical observation so that infection, if it developed, would have been discovered in its earlier stages.

(2) Premature administration of antibiotics might have obscured medical indications for treatment, and might also have led to the development of drum resistant organisms in individuals with lowered resistance to bacterial infection.

(3) There was no accurate knowledge of the number of granulocytes requires by man to prevent infection with this type of granuloctyopenia as occurred in the Marshallese.

The observed situation was not strictly comparable to agranulocytosis with an aplastic marrow as seen following known lethal doses of radiation. In the latter instant, granulocytes fall rapidly with practically none in the circulation and no evidence of granulocyte regeneration when infection occurs. In the present group of individuals exposed to radiation, most counts reached approximately one-fourth the normal value, but the fall to that level was gradual and the presence of immature granulocytes in the peripheral blood during the period of granulocytopenia was indicative of some new granulocyte production. In other words, the bone marrow had not been completely eradicated by the dose of radiation received.

The few individuals that received antibiotics had conditions that would have been treated with antibiotics in the absence of any previous exposure to irradiation. During the fourth and fifth exposure weeks an epidemic of upper respiratory infection occurred. The respiratory infection consisted of moderate malaise, pharyngitis with prominent lymphoid follicles, fever during the first day, and a purulent nasal and tracheal discharge for about 10 days.

It was of interest to determine whether this respiratory infection could be correlated with the dose of radiation received or changes in the leukocyte count. There was no correlation. The respiratory infection in the medical personnel involved in the care and study of the irradiated individuals was similar in incidence and severity.

Earlier today Doctor Friedell commented upon platelets, and these were followed very carefully in the Marshallese.

CLINICAL OBSERVATIONS AND PLATELET COUNTS

Eleven individuals had platelet counts that fell as low as 35,000 to 65,000/mm.[3]. All individuals with platelet counts less than 100,000 per mm.[3] were examined daily for evidence of hemorrhage into the skin, mucous membranes and retina. Urine was examined daily for red cells and albumin. Women were questioned concerning excessive menstruation. The only evidence for any undue bleeding were two women who menstruated profusely at the time of their maximum platelet depression. It was not sufficient to cause them undue concern and subsided without any specific treatment.

THE EFFECTS ON PREGNANCY

Four women in the Rongelap group were pregnant when brought to Kwajalein. Two were in the first trimester, one in the second trimester and one in the third trimester. There were no abnormal symptoms referable to pregnancy. As far as could be determined the pregnancy continued in the normal fashion.

In the Ailinginae group of 69 r, one woman was in the second trimester. Fetal movements were unaffected in the individual in the third trimester. The pregnant women had a marked depression of platelet counts but at no time was there any vaginal bleeding. At the 12-month reexamination of the above women, all had delivered. One baby was born dead; the others were normal.

In the case of the one stillborn, irradiation occurred to the mother either before conception or early in the first trimester. It is possible that the irradiation may have contributed but there is no way to prove this.

SPECIAL EXAMINATION OF EYES

At all followup examinations an ophthalomogist has examined the eyes of all individuals. To date no lesions ascribable to ionizing radiation have been found. Similar studies have been made on the eyes of nonexposed Marshallese and the incidence of eye lesions is identical in the two groups.

SKIN LESIONS AND EPILATION

As mentioned earlier there was burning of the skin. On first examination by the medical team on the ninth post exposure day the exposed people appeared to be in good health and the skin was definitely normal in external appearance. Evidence for the development of skin lesions commenced approximately 2 weeks after exposure.

During the early stages of development of the lesions, itching, burning and slight pain were experienced with the more superficial lesions. With deeper lesions the pain was more severe. The deeper foot lesions were the most painful and caused some of the people to walk on their heels for several days during the acute stages. Some of the more severe lesions of the neck and axillae were painful. There were no constitutional symptoms associated with the skin lesions.

The characteristic sequence of events in the development of the lesions was the occurrence of symptoms, then of black pigmented areas, small in size, which grew larger in size and coalesced. Later the skin began to shed from the inside of the pigmented plaques to the outside, and in some cases resulted in the production of large depigmented areas. In most of the lesions the shedding was limited to the superficial layers of the skin. In some the process continued with the development of superficial ulcers. A few became infected.

The appearance of these skin burns can best be illustrated by referred to chapter III of reference 1 where Kodachrome pictures illustrate the sequence of events.

In addition to the skin burns, loss of hair, spotty in nature, occurred in some of the individuals. The hair grew in again with normal color and texture and the regrowth was complete in all except possibly one middle-aged man in whom it came in somewhat sparsely. Small pieces of skin were removed surgically from some of the burned areas for microscopic study. These pieces of skin demonstrate the typical findings of radiation injury. Some of the skin burns became infected, particularly those on the feet, and were treated locally by cleansing and applications of antibiotic ointments. The skin burns healed in most cases with return of normal color and texture of the skin, and in some cases scars were left with depigmented areas.

The worst burn occurred on the back of the ear of a middle aged man. It produced a permanent scar with absence of pigment and abnormal blood vessels and a slight horny growth of the overlying skin has developed. The skin has been carefully observed at 6 months, 12 months, 2 years, and 3 years after exposure, and there is no evidence at the present time of any breakdown in the early burns of the skin. There is no evidence of the development of cancer at this time. In some the depigmented scars are still evident. The individuals have been seen on two occasions by a plastic surgeon, Dr. Bradford Cannon, of the Harvard Medical School, who feels that no plastic repair is necessary and that the prognosis in general is good.

FACTORS INFLUENCING SEVERITY OF THE LESIONS

Certain lessons were learned from the Marshallese experience.

Burns were caused by direct contact of the radioactive material with the skin. The perspiration as common in the tropics, the delay in decontamination and the difficulties in decontamination certainly favored the development of the skin burns. Those individuals who remained indoors or under trees during the fallout developed less severe skin burns. The children who went wading in the ocean developed fewer lesions of the feet and most of the Americans who were more aware of the dangers of the fallout, took shelter in aluminum buildings and bathed and changed clothes. Consequently they developed only very mild beta burns.

Lastly, a single layer of cotton material offered almost complete protection, as was demonstrated by the fact that skin burns developed almost entirely on the exposed parts of the body.

The prognosis of beta skin burns and radiation burns of the skin is excellently described in chapter III of reference 1.

HEMATOLOGIC OBSERVATIONS

It is generally considered that changes in the blood are the most sensitive biologic indexes of exposure of living human beings to radiation. Accordingly extensive simple hematologic studies were performed on the Marshallese. Since there were no previous hematologic studies on the exposed Marshallese, it was necessary to set up control groups of nonexposed Marshallese of the same age and sex distribution for comparative purposes.

I shall restrict my comments to the findings in the group from Rongelap since the temporal sequence of events are identical in all of the exposed groups. Of course the depression was less marked in the less severely exposed groups.

NEUTROPHILE COUNT

The absolute neutrophile count of both the younger and older age groups fell during the second week to a value approximating 70 to 80 percent of that of the controls. Following the depression there was an oscillation roughly around the control value until about the 30th postexposure day at which time there was a progressive decrease in the blood count with minimum values being attained around the 45th day after exposure. It is of interest that the depression in the children less than 5 years of age was greater than in the individuals who were greater than 5 years of age.

Following this maximal depression there was a slow return of the neutrophile counts toward normal. However, at 6 months they were still depressed. At 1 year and 2 years the neutrophile counts were back to the control level. However, at 3 years there was a drop in the absolute mean neutrophile count but this also occurred in the control population. It is not known whether lower counts represent a population trend as has been noted in the Japanese for both irradiated and nonirradiated populations, or whether it is merely a statistical fluctuation that is to be expected in this type of study. More work is necessary on this point.

LYMPHOCYTE COUNT

By 3 days the lymphocytes dropped to 50 percent of the controls. The percent drop in the children less than 5 years of age was greater than that of the people older than 5 years. The lymphocyte count remained at approximately the same level through the exposure period. At 6 months, 12 months, 2 years, and 3 years, the level, though increasing, had not quite reached that of the control population.

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PLATELETS

The maximum depression in platelets was obtained approximately 8 to 30 days after exposure in contrast to laboratory animals that attain their minimum values between the 10th and 15th days after exposure. In this case the children under 10 years of age had a greater percentage drop than those who were older. The platelets began to recover after the 30th day, attain a maximum about the 45th day. There was then a secondary drop with a leveling off for the remainder of the postexposure period, and at 6 months, 12 months, 2 years, and 3 years, slow recovery was still underway. The levels of the population were approaching the controls but have not yet reached it.

In all of the hematologic studies mentioned above, it is stated that the present levels are not equal to that of the control population. However, I wish to emphasize that the current levels of the blood cells of all types is more than adequate to take care of the infections and the various troubles of everyday existence. This statistical expression of an inadequate recovery probably represents the residual radiation injury that is of considerable interest to study but does not appear to be overtly harmful to the individuals. One can be reasonably confident in this because they are not faring less well in resistance to disease than are the Marshallese who were nonexposed and living in the same area.

INTERNAL ABSORPTION OF RADIONUCLIDES

During the 2 days before evacuation, the Rongelap people lived under conditions of extreme contamination without any concerted efforts to protect themselves against the dangers of internal contamination. These individuals drank contaminated water, and ate their natural foodstuffs which were contaminated externally. Their hands were contaminated: they inhaled and obviously ingested certain indeterminate amounts of material.

The body burdens of isotopes in these individuals was evaluated by radiochemical analysis of the urine of the exposed people and assisted by studies on swine. These swine were removed from the island at a later date. The urinary and fecal excretion was studied and ultimately the animals were killed. Extensive radiochemical analyses were made of their entire bodies. By comparison, approximations of body burdens of radionuclides was made. From a combination of urinary excretion and animal studies estimates were made of the probable body burden.

Rare and alkaline earths accounted for about 70 percent of the urine activity. Strontium 89 was about at the maximum permissible level at 1 day. Iodine 131 and other members of the iodine family which had to be present early, resulted in a dose of radiation to the thyroid glands, estimated between 100 and 150 rep. To this of course, must be added the penetrating external gamma component. By 6 months radiation was barely detectable in the urine. At 2 years from analysis of pooled urine samples and individual samples, very tiny amounts of strontium 90, calcium 45, praseodymium and cesium were present. Studies were performed both at United States Naval Radiological Defense Laboratory, and Walter Reed Army Medical Center.

The results of the 3-year radiochemical analysis of the urines that were recently collected are not completed as yet.

It was believed that the body burdens of these people was very low and probably biologically insignificant. However it was decided to bring some of the individuals to the United States for study with the total body gamma counter at the Argonne National Laboratory. This decision was made not because of any fear but because the analysis of the urine and the animal analysis were an indirect means to obtain probable body burdens.

It was obviously desirable to obtain a firm direct measurement of the body burden from the scientific standpoint and to determine the precise body burdens. Four individuals from the Rongelap group, 2 from the Utirik group, and 1 control Marshallese—a total of 7—were brought to the United States and taken to the Argonne National Laboratory. There, under the direction of Doctors Marinelli, Rose, and Miller, the total body gamma activity was measured. The results are yet incomplete and have to be analyzed further. It was found that the exposed Marshallese had counts that were higher than nonexposed peoples in the United States. However, the values were far below the current permissible levels.

Since there has been some misunderstanding in the press about children being brought to the United States for study, I would like to state that all the individuals brought to the United States were adults, with the exception of one 16-year-old boy. They have subsequently been returned to the Marshall Islands.

THE CONTINUING STUDY OF THE MARSHALLESE

My associate in the Medical Department of Brookhaven National Laboratory, Dr. Robert A. Conard, a member of the original team that took care of and studied the Marshallese, and director of the 2- and 3-year surveys, has retained an abiding interest in the Marshallese. On behalf of the Atomic Energy Commission and Brookhaven National Laboratory, he has undertaken the continuing responsibility of yearly surveys of these people. These surveys are being made possible by the cooperation of the Medical Department of the United States Navy and its activities, the Medical Research Institute at Bethesda, Md., and the United States Naval Radiological Defense Laboratory in San Francisco. The continuing project is a joint effort directed by Dr. Conard and participated in by the Medical Department of Brookhaven National Laboratory, the two Navy institutions mentioned earlier, and interested physicians and scientists of various American universities and medical schools. The probabilities of getting a good scientific followup are excellent.

One cannot leave this tremendously important subject of fallout and the unfortunate accident that occurred in the Marshall Islands in 1954 without the frank recognition that late effects of ionizing radiation are possible. Many late effects have been observed in man and in animals. These are condensed in detail in the National Academy of Sciences report (reference 8). Accordingly, a search for late effects is an essential part of the continuing survey.

A summary of the 3-year status of these people, which will be reported in detail in reference 22, now being prepared, follows:

FERTILITY

Effect of radiation exposure on fertility is difficult to assess in the Marshallese. If there has been any effect on fertility, it must have been very short lived, since pregnancies are occurring normally and at rates similar to other groups of Marshallese.

PREGNANCY

There has been no apparent effect of radiation on the course of pregnancy in the Marshallese. Since the delivery of the 4 women who were pregnant at the time of the event, there have been 12 pregnancies which have terminated. Ten of these terminated normally, one terminated in a stillbirth, and one baby died several hours after birth, apparently of an infection of the cord. The lack of vital statistics makes this data difficult to interpret. However, it does not appear that this incidence of stillbirths is greater than that of other comparable native groups in the mid-Pacific area.

EFFECTS ON THE FETUS

The three babies irradiated in utero have not shown any abnormalities such as was observed in some of the Japanese babies irradiated in utero. For example, microcephaly.

GROWTH AND DEVELOPMENT

On each resurvey the exposed and control children have been matched for age and sex. Measurements on growth and development have been carried out. Anthropometric measurements have been incompletely analyzed as yet. Since the numbers of children are small, the data is not easily subjected to statistical analysis. There were 17 children less than 7 years of age and 24 less than 16 years of age at the time of exposure. However, there does appear to be a statistical evidence suggestive of a slight impairment of growth and development as measured by comparison of height and weight in the control and exposed children. You cannot look at these children and pick out any abnormalities.

I would like to comment on this rather emphatically, because of the headlines that I saw a few minutes ago. There is no gross stunting of the growth. It can only be detected by a careful statistical analysis of the data, by taking measurements of weight and height.

SHORTENING OF LIFE SPAN

In animals, the evidence for shortening of life span is quite good. It is evidence that the life shortening is some function of the dose of radiation. However, the extrapolation from mice to man is extremely difficult. It is unlikely that any good statistical analysis can be made on the Marshallese because of the small numbers of individuals and the uncertainty of the precise birth date in the older groups, prior to the American occupation in 1944.

There has been one death in the Rongelap group who, at autopsy, showed evidence of heart disease. In the larger group from Utirik there have been five deaths. The number of deaths is comparable in both groups, one having received 175 r. and the latter only 14 r. To date, one must conclude that there has been no significant evidence for premature aging or shortening of the life span of the Marshallese.

LEUKEMIA AND CANCER

Leukemia is one of the things that is known to have occurred in the Japanese and is prevalent in irradiated laboratory animals. To date, no leukemia has occurred and there is no evidence of leukemic tendencies. This is being studied intensively by the use of alkaline phosphatase studies on the granulocytes and basophile counts on the blood. It has been shown by the studies of Moloney et al. in Japan that a basophilia and decrease in alkaline phosphatase precedes the development of leukemia. They picked up a precursor tendency that is detectable prior to the frank morphological picture of general leukemia.

Genetic effects, I think, I will defer comment on, since I am not a geneticist. The number is small, and I see little chance of detecting anything of note in the Marshallese.

Representative HOLIFIELD. Is it not true that, if the male and female are married to a group that have been irradiated, there is a much greater chance of the genes being effected than if one irradiated person and a nonirradiated person were married?

Dr. CRONKITE. Yes: I am sure the probability of detecting is greater by consanguineous marriage than by nonconsanguineous. I am sure this is a subject that Dr. Russell will go into in considerable detail, and I will have to confess relative ignorance on the subject.

LONG-TERM EFFECTS OF INTERNALLY DEPOSITED RADIONUCLIDES

The very small amounts of radioactive materials that are deposited internally are, by themselves, inadequate to produce serious, long-term effects. However, the subject is complicated by the fact that the individuals had a substantial initial insult from whole-body radiation. In addition to the whole-body radiation, the thyroid gland received approximately 100 to 150 r. e. p. from the short-lived iodine family. It has been reported that irradiation of the thyroid area in early life increases the incidence of cancer of the thyroid. Accordingly, thyroid function and the possibility of thyroid cancer is being studied in the Marshallese children. To date, there is no evidence of abnormality.

Before concluding, I cannot refrain from expressing my personal opinion and conviction on two aspects of the fallout problem.

First, the acute and long-term hazards of fallout, such as would occur following the use of thermonuclear devices in warfare, are simply unthinkable. The widespread contamination over continental areas from multiple detonations of thermonuclear devices over populated areas would produce radiation hazards for all living things and for generations to come. These hazards are rather well understood. These hazards cannot be considered on the usual calculated risk basis of warfare in the past. One can only make a plea that an enlightened world will demand that their representatives in government also appreciate these hazards and with this recognition bring every conceivable

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Second, the worldwide, low-level radiation of today from diverse
ources has been analyzed thoughtfully by competent people, individ-
ally and in assembly. Note the sober and realistic reports of the
National Academy of Sciences, the British Medical Research Council,
nd the United Nations. These reports point out the multiple sources
f radiation in our lives today and the necessity for continuous scru-
ny. Let us not confuse unavoidable radiation exposure with radia-
on hazard. Let us not lose sight of the multiple sources by undue pre-
ccupation with worldwide fallout. Let us not be so preoccupied with
adiation in general that we forget about industrial pollution of our
nvironment in general by nonradioactive but toxic substances.

Lastly, the incidence of leukemia was apparently increasing prior
o the development of atomic energy. Why?

Representative HOLIFIELD. Thank you very much, Dr. Cronkite,
for that fine presentation.

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Representative HOLIFIELD. I think the committee is conscious of your deep feeling on the fact that regardless of how this testimony comes out in relation to the dangers of bomb testing at the rate they have been made, that there is a tremendous concern as to war with nuclear weapons. If the consensus of scientific opinion is that there has been no appreciable damage in testing at the rate we have had it to date, it is certainly not to be taken that there is any less danger from a full-scale nuclear type of attack in war.

Are there any questions of Dr. Cronkite?

Representative COLE. Yes, Mr. Chairman, I would like to ask 1 or 2.

Doctor, for my edification, would you indicate the difference, if any, and the biological consequences in the exposure to cosmic radiation as against fission radiation?

Dr. CRONKITE. I do not think there would be any qualitative difference. I think it is purely a matter of quantity. The cosmic radiation is low, if it were possible to increase the cosmic radiation the effects to be expected would be the same as with any source of radiation—external penetrating radiation.

Representative COLE. Then it is your understanding that the result and effect on the anatomy would be the same, whether from cosmic radiation or induced or artificial or fission radiation?

Dr. CRONKITE. I believe so, Mr. Cole.

Representative COLE. From what you know of the observations that have been made as a result of the studies of the Japanese population, who are exposed to radiation from the weapons fission, did those lessons vary in any degree with the lessons and observations that have resulted from the Marshallese people who were exposed?

Dr. CRONKITE. The only significant difference in the response is the Japanese were not exposed to fission products deposited in their environment but to the initial radiation from the bomb and accordingly did not have any skin burns resulting from radiation. Their skin burns were thermal in origin.

I would say that there is remarkable correspondence.

Representative COLE. I am referring to the Hiroshima and Nagasaki people; not the fishermen.

Dr. CRONKITE. I was referring to the Hiroshima and Nagasaki group. At Hiroshima and Nagasaki they were exposed to initial gamma radiation from the bomb. The fission products were not deposited on the ground. So that the Japanese there did not receive any skin burns due to contacting material. In this respect the Marshallese differ from the Japanese because they had a mixture of the radiation injury produced by the penetrating component of the gamma rays from the fission products and by the direct contact of the material on the skin with the resulting beta burns.

Representative COLE. You concluded your very fine statement with a rather imponderable question, and I am going to ask you to suggest possible answers to the question which you have raised.